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SPECIFICATION.

TO ALL WHOM IT MAY CONCERN:

BE IT KNOWN THAT WE, NAOTO JIKUTANI, a citizen of Japan residing at Miyagi, Japan, SHUNICHI SATO, a citizen of Japan residing at Miyagi, Japan and TAKASHI TAKAHASHI, a citizen of Japan residing at Miyagi, Japan have invented certain new and useful improvements in

LASER DIODE HAVING AN ACTIVE LAYER CONTAINING N AND
OPERABLE IN A 0.6 μ m WAVELENGTH BAND

of which the following is a specification:-

1 BACKGROUND OF THE INVENTION

 The present invention is a continuation-in-part application of the United States patent application 09/289,955 filed April 13, 1999.

5 The present invention generally relates to optical semiconductor devices and more particularly to an optical semiconductor device including a laser diode operable in a 0.6 μm wavelength band.

 The optical wavelength band of 0.6 μm is used
10 extensively in storage devices such as an optical disk drive or a magneto-optical disk drive for optical writing or reading of information. Further, the optical wavelength band of 0.6 μm is important in optical telecommunication that is conducted by using plastic
15 optical fibers.

 Thus, intensive investigations are being made in relation to a laser diode of an AlGaInP system that produces an output optical beam with the optical wavelength band of 0.6 μm . The laser diode using the
20 AlGaInP system is also important in color display devices as an optical source of red to green colors. It should be noted that the AlGaInP system is a III-V material providing the largest bandgap (2.3 eV or 540 nm wavelength) while simultaneously maintaining a lattice
25 matching with a GaAs substrate.

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1 On the other hand, such a laser diode using
the AlGaInP system for the active layer thereof suffers
from the problem of poor confinement of carriers,
particularly electrons, in the active layer. More
5 specifically, carriers escape easily from the active
layer to adjacent upper and/or lower cladding layers due
to the small band discontinuity formed at the
heterojunction interface between the AlGaInP active
layer and the adjacent cladding layers. Associated with
10 such a small band discontinuity and resultant weak
carrier confinement, the conventional AlGaInP laser
diodes have suffered from the problem of large
temperature dependence for the threshold characteristic
of the laser oscillation. This problem of poor
15 temperature characteristic of the laser diode is
pronounced further when the bandgap of the active layer
is increased for decreasing the laser oscillation
wavelength by using a quantum well structure for the
active layer.

20 In order to avoid the problem of overflowing
of the carriers away from the active layer, the Japanese
Laid-Open Patent Publication 4-114486 describes the use
of a multiple quantum barrier (MQB) structure for the
carrier blocking layer. Further, Hamada, H. et al.,
25 Electronics Letters, vol.28, no.19, 10th September 1992,

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1 pp.1834-1836, describes the use of a strained MQW
structure strained with a compressive stress. According
to Hamada et al., op. cit., a continuous laser
oscillation with a wavelength of as small as 615 nm is
5 achieved by forming the strained MQW structure by using
a quantum well layer having a composition of
(Al_{0.08}Ga_{0.92})_{0.45}In_{0.55}As in combination with a barrier
layer and a GaAs substrate. However, the laser diode of
thus produced has an unsatisfactory temperature
10 characteristic, indicating that the desired, effective
confinement of carriers is not realized.

Further, there is another proposal of a laser
diode operable in the 600 nm wavelength band by using
the material system of AlGaInP in combination with a
15 substrate other than GaAs. For example, the Japanese
Laid-Open Patent Publication 6-53602 proposes the use of
an MQW structure including GaInP quantum well layers and
GaInP barrier layers for the active layer in combination
with a GaP substrate and AlGaP cladding layers. The
20 foregoing reference further teaches the use of N as an
impurity element forming an isoelectronic trap. This
device, however, cannot provide the satisfactory
confinement of carriers in the active layer. Thereby,
the laser diode is characterized by a poor temperature
25 characteristic.

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Unfortunately, such a III-V material system containing N generally shows a severe bowing in the bandgap due to the large electronegativity of N, and the desired increase of the bandgap is not achieved in the foregoing lattice matching composition, contrary to the prediction of the foregoing Japanese Laid-Open Patent Publication 7-7223. Further, in view of the existence of extensive immiscibility gap in the III-V material system containing N, formation of a III-V crystal containing such a large amount of N is not possible even when a non-equilibrium growth process such as MBE process or MOCVD process is used.

1 Thus, it has been difficult to achieve the
laser oscillation at the 600 nm wavelength band even
when other material systems are used. The use of the
AlGaInP system, on the other hand, cannot provide the
5 desired efficient confinement of carriers in the active
layer due to the insufficient band discontinuity at the
heterojunction interface between the active layer and
the cladding layer.

10 SUMMARY OF THE INVENTION

 Accordingly, it is a general object of the
present invention to provide a novel and useful laser
diode operable in the 600 nm wavelength band wherein the
problems are eliminated.

15 Another and more specific object of the
present invention to provide a laser diode operable in
the 600 nm wavelength band with effective confinement of
carriers in the active layer of the laser diode.

 Another object of the present invention is to
20 provide a laser diode, comprising:

 a substrate of a first conductivity type;

 a first cladding layer having said first
conductivity type, said first cladding layer being
formed on said substrate epitaxially;

25 an active layer of a group III-V compound

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1 semiconductor material formed epitaxially on said first
cladding layer;

a second cladding layer having a second,
opposite conductivity type, said second cladding layer
5 being formed on said active layer epitaxially;

a first electrode injecting first type
carriers having a first polarity into said active layer;
and

a second electrode injecting second type
10 carriers having a second, opposite polarity into said
active layer,

said active layer having a composition of
GaInNP containing therein N as a group V element.

According to the present invention, a large
15 band discontinuity is guaranteed at the interface
between the active layer and the first or second
cladding layer as a result of the use of GaInNP for the
active layer, and the efficiency of carrier confinement
is improved substantially. By adjusting the amount of N
20 in the GaInNP active layer, it becomes possible to set
the band offset at the interface between the active
layer and the first or second cladding layer as desired.
Thereby, the laser diode shows an excellent temperature
characteristic and operates stably at the room
25 temperature environment. Further, as a result of the

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1 use of GaInNP for the active layer, the laser diode
operates in the visible wavelength band including the
600 nm band. As the active layer of GaInNP is free from
reactive Al, the growth of the active layer is conducted
5 easily, without inducing island growth or associated
problem of deterioration of crystal quality.

Another object of the present invention is to
provide a vertical-cavity laser diode, comprising:

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10 a substrate having a first conductivity type;
a first optical reflector provided on said
substrate;

a first cladding layer having said first
conductivity type on said first optical reflector in an
epitaxial relationship with said substrate;

15 an active layer of a group III-V compound
semiconductor material formed epitaxially on said first
cladding layer;

a second cladding layer having a second,
opposite conductivity type on said active layer in an
20 epitaxial relationship with said active layer;

a second optical reflector provided on said
second cladding layer;

a first ohmic electrode provided in ohmic
contact with said substrate; and

25 a second ohmic electrode provided in ohmic

1 contact with said second cladding layer;

said active layer having a composition of GaInNP containing therein N as a group V element.

According to the present invention, an
5 efficient vertical cavity laser diode operable in the visible wavelength band is obtained. As a result of use of GaInNP for the active layer, a large band discontinuity is guaranteed at the interface between the active layer and the first or second cladding layer, and
10 the efficiency of carrier confinement is improved substantially. By adjusting the amount of N in the GaInNP active layer, it becomes possible to set the band offset at the interface between the active layer and the first or second cladding layer as desired. Thereby, the
15 laser diode shows an excellent temperature characteristic and operates stably at the room temperature environment. Further, as a result of the use of GaInNP for the active layer, the laser diode operates in the visible wavelength band including the
20 600 nm band. As the active layer of GaInNP is free from reactive Al, the growth of the active layer is conducted easily, without inducing island growth or associated problem of deterioration of crystal quality.

Another object of the present invention is to
25 provide a method of fabricating a compound semiconductor

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1 device, comprising the step of:

(a) forming a first group III-V compound semiconductor layer epitaxially on a substrate;

(b) exposing a surface of said first group
5 III-V compound semiconductor layer to an atmosphere containing N;

(c) forming, after said step (b), a second group III-V compound semiconductor layer on said first group III-V compound semiconductor layer epitaxially,
10 said second group III-V compound semiconductor layer containing therein N as a group V element,

wherein said atmosphere is substantially free from a group III element.

According to the present invention, a part of
15 the atoms constituting the group V element of the first group III-V compound semiconductor layer are replaced with N, and the epitaxial growth of the second group III-V compound semiconductor layer on the first group III-V compound semiconductor layer is facilitated
20 substantially.

Another object of the present invention is to provide a semiconductor layered structure, comprising:

a first epitaxial layer of AlGaInNP having a composition represented by compositional parameters x_1 ,
25 y_1 and z_1 ($0 \leq x_1 < 1$, $0 < y_1 \leq 1$, $0 < z_1 < 1$) as

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1 $\text{Al}_{x1}\text{Ga}_{y1}\text{In}_{(1-x1-y1)}\text{N}_{z1}\text{P}_{(1-z1)}$;

a second epitaxial layer of AlGaInP having a composition represented by compositional parameters $x2$ and $y2$ as $\text{Al}_{x2}\text{Ga}_{y2}\text{In}_{(1-x2-y2)}\text{P}$, said second epitaxial
5 layer being disposed adjacent to said first epitaxial layer; and

a third epitaxial layer of AlGaInP having a composition represented by compositional parameters $x3$ and $y3$ as $\text{Al}_{x3}\text{Ga}_{y3}\text{In}_{(1-x3-y3)}\text{P}$, said third epitaxial
10 layer being disposed between said first and second epitaxial layers, said first through third epitaxial layers maintaining an epitaxy with each other;

wherein said compositional parameters are set so as to satisfy the relationship:

15 $0 \leq x3 < x2 \leq 1; 0 < y3 \leq 1.$

According to the present invention, the use of AlGaInNP composition, which includes N, for the first layer enables an efficient incorporation of N thereinto as a result of the interaction between Al and N.

20 Thereby, the content of N thus incorporated into the first epitaxial layer can be controlled by controlling the content of Al therein. As a result of the improvement in the efficiency of incorporation of N, the amount of the N-source used in the epitaxial process is
25 reduced and the cost of forming the layered structure is

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1 reduced. As such a layered structure contains N in the
first epitaxial layer with a substantial amount, a
variety of band structures, hitherto not possible, can
be realized easily.

5 Another object of the present invention is to
provide a semiconductor light-emitting device,
comprising:

a substrate of a first conductivity type;
a first cladding layer of AlGaInP of said
10 first conductivity type provided on said substrate;
an active layer of undoped AlGaInNP provided
on said cladding layer; and

a second cladding layer of AlGaInP of a
second, opposite conductivity type provided on said
15 active layer;

said active layer having a composition
represented by compositional parameters x_1 , y_1 and z_1 as
 $\text{Al}_{x_1}\text{Ga}_{y_1}\text{In}_{(1-x_1-y_1)}\text{N}_{z_1}\text{P}_{(1-z_1)}$ ($0 \leq x_1 < 1$, $0 < y_1 \leq 1$, $0 <$
 $z_1 < 1$), said first cladding layer having a composition
20 represented by compositional parameters x_2 and y_2 as
 $\text{Al}_{x_2}\text{Ga}_{y_2}\text{In}_{(1-x_2-y_2)}\text{P}$,

wherein there is provided an intermediate
layer of AlGaInP between said first cladding layer and
said active layer, said intermediate layer having a
25 composition represented by compositional parameters x_3 ,

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1 y_3 and z_3 as $Al_{x_3}Ga_{y_3}In_{(1-x_3-y_3)}P$,

 said compositional parameters satisfying the
relationship:

$$0 \leq x_3 < x_2 \leq 1; 0 < y_3 \leq 1.$$

5 According to the present invention, the use of
AlGaInNP composition, which includes N, for the active
layer enables an efficient incorporation of N therein to
as a result of the interaction between Al and N.
Thereby, the content of N thus incorporated can be
10 controlled by controlling the content of Al of the
active layer. As a result of the improvement in the
efficiency of incorporation of N, the amount of the N-
source used in the epitaxial process for forming the
AlGaInNP active layer is reduced and the cost of forming
15 the layered structure is reduced. By interposing the
intermediate layer containing minimum amount of Al
between the first cladding layer and the active layer,
the segregation of N at the lower boundary of the active
layer is effectively eliminated, and the quality of the
20 AlGaInNP crystal constituting the active layer is
improved. As the active layer contains both Al and N,
the decrease of the bandgap energy caused by the
incorporation of N into the active layer is compensated
for by Al, and the light-emitting device produces a
25 short optical wavelength radiation. Due to the downward

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1 shifting of the conduction band and valence band as a
result of incorporation of N into the active layer
AlGaInNP, there occurs an effective confinement of the
electrons in the active layer.

5 Another object of the present invention is to
provide a semiconductor light-emitting device,
comprising:

 a substrate of a first conductivity type;
 a first cladding layer said first conductivity
10 type provided on said substrate;
 a first optical waveguide layer of undoped
AlGaInP provided on said first cladding layer;
 an active layer of undoped AlGaInNP provided
on said optical waveguide layer;
15 a second optical waveguide layer of undoped
AlGaInP provided on said active layer; and
 a second cladding layer of a second, opposite
conductivity type provided on said second optical
waveguide layer

20 said active layer having a composition
represented by compositional parameters x_1 , y_1 and z_1 as
 $Al_{x_1}Ga_{y_1}In_{(1-x_1-y_1)}N_{z_1}P_{(1-z_1)}$ ($0 \leq x_1 < 1$, $0 < y_1 \leq 1$, 0
< $z_1 < 1$), said first optical waveguide layer having a
composition represented by compositional parameters x_2
25 and y_2 as $Al_{x_2}Ga_{y_2}In_{(1-x_2-y_2)}P$,

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1 wherein there is provided an intermediate
layer of AlGaInP between said first optical waveguide
layer and said active layer, said intermediate layer
having a composition represented by compositional
5 parameters x_3 and y_3 as $\text{Al}_{x_3}\text{Ga}_{y_3}\text{In}_{(1-x_3-y_3)}\text{P}$,

 said compositional parameters satisfying the
relationship

$$0 \leq x_3 < x_2 \leq 1; 0 < y_3 \leq 1.$$

 According to the present invention, the use of
10 AlGaInNP composition, which includes N, for the active
layer enables an efficient incorporation of N thereinto
as a result of the interaction between Al and N.
Thereby, the content of N thus incorporated can be
controlled by controlling the content of Al of the
15 active layer. As a result of the improvement in the
efficiency of incorporation of N, the amount of the N-
source used in the epitaxial process for forming the
AlGaInNP active layer is reduced and the cost of forming
the layered structure is reduced. By interposing the
20 intermediate layer containing minimum amount of Al
between the first optical waveguide layer and the active
layer, the segregation of N at the lower boundary of the
active layer is effectively eliminated, and the quality
of the AlGaInNP crystal constituting the active layer is
25 improved. As the active layer contains both Al and N,

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1 the decrease of the bandgap energy caused by the
incorporation of N into the active layer is compensated
for by Al, and the light-emitting device produces a
short optical wavelength radiation. Due to the downward
5 shifting of the conduction band and valence band as a
result of incorporation of N into the active layer
AlGaInNP, there occurs an effective confinement of the
electrons in the active layer.

Another object of the present invention is to
10 provide a method of fabricating a semiconductor layered
structure comprising a first epitaxial layer of AlGaInNP
having a composition represented by compositional
parameters x_1 , y_1 and z_1 as $\text{Al}_{x_1}\text{Ga}_{y_1}\text{In}_{(1-x_1-y_1)}\text{N}_{z_1}\text{P}_{(1-z_1)}$ ($0 \leq x_1 < 1$, $0 < y_1 \leq 1$, $0 < z_1 < 1$), a second
15 epitaxial layer of AlGaInP having a composition
represented by compositional parameters x_2 and y_2 as
 $\text{Al}_{x_2}\text{Ga}_{y_2}\text{In}_{(1-x_2-y_2)}\text{P}$, said second epitaxial layer being
disposed adjacent to said first epitaxial layer, and a
third epitaxial layer of AlGaInP having a composition
20 represented by compositional parameters x_3 and y_3 as
 $\text{Al}_{x_3}\text{Ga}_{y_3}\text{In}_{(1-x_3-y_3)}\text{P}$, said third epitaxial layer being
disposed between said first and second epitaxial layers,
said first through third epitaxial layers maintaining an
epitaxy with each other, said compositional parameters
25 being set so as to satisfy the relationship ($0 \leq x_3 < x_2$

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1 $\leq 1; 0 < y_3 \leq 1$),

said method comprising the steps of:

forming said first epitaxial layer by using a
metal organic compound of Al for the source of Al;

5 forming said second epitaxial layer by using a
metal organic compound of Al for the source of Al; and

forming said third epitaxial layer by using a
metal organic compound of Al for the source of Al.

According to the present invention, it becomes
10 possible to control the content of N in the epitaxial
layers by controlling the Al content thereof. For
example, it becomes possible to increase the N content
of the first epitaxial layer by increasing the Al
content thereof. Further, the quality of the first
15 epitaxial layer is improved by decreasing or minimizing
the Al content of the third epitaxial layer, such that
there occurs no segregation of N at the interface
between the first epitaxial layer and the third
epitaxial layer.

20 Other objects and further features of the
present invention will become apparent from the
following detailed description of the invention when
read in conjunction with the attached drawings.

25 BRIEF DESCRIPTION OF THE DRAWINGS

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1 FIG.1 is a diagram explaining a first
embodiment of the present invention;

 FIG.2 is another diagram explaining the first
embodiment of the present invention;

5 FIG.3 is a diagram showing the layered
structure according to a second embodiment of the
present invention;

 FIG.4 is a diagram showing the PL spectrum of
the layered structure of FIG.3;

10 FIG.5 is a diagram showing the construction of
a laser diode according to a third embodiment of the
present invention;

 FIG.6 is a diagram showing the construction of
a laser diode according to a fourth embodiment of the
15 present invention;

 FIG.7 is a diagram showing the band structure
of the laser diode of FIG.6;

 FIGS.8A and 8B are diagrams showing the
construction of a laser diode according to a fifth
20 embodiment of the present invention;

 FIG.9A and 9B are diagrams showing the
construction of a laser diode according to a sixth
embodiment of the present invention;

 FIG.10 is a SIMS profile for the structure of
25 FIG.9B;

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1 FIG.11 is a diagram showing the possible band
structure of the laser diode of FIG.9B;

 FIG.12 is another diagram showing the band
structure of the laser diode of FIG.9B;

5 FIG.13 is a diagram showing the construction
of a laser diode according to a seventh embodiment of
the present invention;

 FIG.14 is a diagram showing the construction
of a laser diode according to an eighth embodiment of
10 the present invention;

 FIG.15 is a diagram showing the construction
of a laser diode according to a ninth embodiment of the
present invention;

 FIGS.16A and 16B show the band structure of
15 the laser diode of FIG.15;

 FIG.17 is a diagram showing the construction
of an optical disk drive according to a tenth embodiment
of the present invention;

 FIG.18 is a diagram showing the construction
20 of an optical transmission system according to an
eleventh embodiment of the present invention;

 FIGS.19A - 19F are diagrams showing various
possible band structures for a laser diode according to
a twelfth embodiment of the present invention;

25 FIGS.20A and 20B are diagrams showing the

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1 effect of strain on the band structure in the laser
diode of the twelfth embodiment of the present
invention;

FIG.21 is a diagram showing the construction
5 of a laser diode according to the twelfth embodiment of
the present invention;

FIG.22 is a diagram showing the construction
of a laser diode according to a thirteenth embodiment of
the present invention;

10 FIG.23 is a diagram showing the construction
of a laser diode according to a fourteenth embodiment of
the present invention;

FIG.24 is a diagram showing the construction
of a laser diode according to a fifteenth embodiment of
15 the present invention;

FIG.25 is a diagram showing a layered
structure according to a sixteenth embodiment of the
present invention;

FIG.26 is a PL spectrum observed for the
20 layered structure of FIG.25;

FIG.27 is a SIMS profile observed for the
layered structure of FIG.25;

FIG.28 is a diagram showing the construction
of a laser diode according to a seventeenth embodiment
25 of the present invention;

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1 FIG.29 is a diagram showing the construction
of a semiconductor layered structure according to an
eighteenth embodiment of the present invention;

 FIG.30 is a diagram showing the construction
5 of the semiconductor layered structure of FIG.29 as
applied to a light-emitting semiconductor device;

 FIG.31 is a diagram showing the effect of Al
on the incorporation of N into a III-V semiconductor
layer;

10 FIG.32 is a diagram showing the construction
of a laser diode according to a nineteenth embodiment of
the present invention;

 FIG.33 is a diagram showing the construction
of a laser diode according to a twentieth embodiment of
15 the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[PRINCIPLE]

 The present invention provides an optical
20 semiconductor device operable in the visible wavelength
band of 0.6 μm such as 630 nm or 650 nm with high
efficiency and excellent stability, by using a mixed
crystal of GaInNP for the active layer in combination
with a cladding layer of a mixed crystal of AlGaInP.

25 The inventor of the present invention has

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1 previously discovered that the bandgap of an AlGaInP
mixed crystal is reduced substantially by adding thereto
a small amount of N as a group V element. The mixed
crystal thus containing N has a composition represented
5 as AlGaInNP. Further, such an admixing of N results in
a decrease of energy both in the conduction band and in
the valence band, and the efficiency of electron
confinement in the potential well, formed in the
conduction band of the AlGaInNP active layer sandwiched
10 by a pair of AlGaInP cladding layers, is improved
substantially. While such an addition of N results in a
formation of a small potential bump in the valence band
of the AlGaInNP active layer, the problem of formation
of such a potential bump is easily resolved and the
15 potential bump is converted to a potential well by
merely choosing the composition of the AlGaInP cladding
layers sandwiching the AlGaInNP active layer
therebetween appropriately. It should be noted that the
amount of decrease of the energy level caused as a
20 result of incorporation of N is smaller in the valence
band than in the conduction band, and there is formed an
effective potential well both in the conduction band and
in the valence band. The AlGaInNP active layer further
has an advantageous feature of lattice matching with the
25 GaAs substrate due to the effect of N that decreases the

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1 lattice constant of the AlGaInP mixed crystal. Because
of the large band discontinuity of the potential well
appearing particularly in the conduction band, the
electrons are confined effectively in the AlGaInNP
5 active layer and the laser diode operates stably in the
room temperature environment.

In order to achieve such a desired relative
shifting of the conduction band and the valence band in
the mixed crystal of AlGaInNP, on the other hand, it is
10 necessary to incorporate N with a concentration of at
least $3 \times 10^{19} \text{cm}^{-3}$. This concentration level of N
substantially exceeds the concentration level of N
introduced in an AlGaInP mixed crystal as an impurity
element forming an isoelectronic trap. It should be
15 noted that an isoelectronic trap is used commonly for
converting an AlGaInP mixed crystal to a mixed crystal
of the direction transition type.

When N is introduced in the AlGaInP mixed
crystal with such a substantial amount, on the other
20 hand, there arises a problem in that the quality of the
resultant AlGaInNP mixed crystal is deteriorated
substantially. As will be explained later in detail
with reference to a preferred embodiment, such a
substantial incorporation of N into a III-V mixed
25 crystal containing Al invites a substantial formation of

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1 rough surface in the crystal layer of the mixed crystal,
indicating the cause of the deterioration in the crystal
quality, while the deterioration of the crystal quality
facilitates non-optical recombination of carriers and
5 the efficiency of the laser diode is deteriorated
inevitably when such a III-V mixed crystal is used for
the active layer of the laser diode. For example, the
laser diode may show a large threshold current for laser
oscillation.

10 On the other hand, the inventor of the present
invention has newly discovered that there occurs no such
deterioration in the crystal quality when N is
introduced into a mixed crystal of GaInP, even in such a
case in which the concentration of N exceeds the
15 foregoing concentration level of $3 \times 10^{19} \text{cm}^{-3}$. It is
believed that the exclusion of reactive Al, which tends
to cause a three-dimensional growth, from the component
constituting a group III-V mixed crystal contributes to
the formation of high-quality III-V mixed crystal of
20 GaInNP.

Further, such an exclusion of Al from the
component of the group III-V mixed crystal reduces the
number of the components constituting the III-V mixed
crystal, while such a reduction in the number of the
25 components reduces the tendency of immiscibility of the

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1 component elements, which is pertinent to such a multi-
component mixed crystal system. It should be noted that
such a III-V mixed crystal containing N generally has a
composition showing immiscibility and the growth thereof
5 by an equilibrium process is impossible. Thus, it has
been necessary to employ a non-equilibrium growth
process such as an MBE (molecular beam epitaxy) process
or an MOCVD (metal-organic chemical vapor deposition)
process in order to grow such a III-V mixed crystal
10 containing N.

In the present invention, the foregoing
problems pertinent to the AlGaInNP mixed crystal system
is avoided successfully by using the GaInNP mixed
crystal for the active layer of the laser diode.
15 Thereby, it was discovered that it is preferable to
increase the concentration of Ga in the mixed crystal,
as the increased concentration of Ga in the mixed
crystal also increases the allowable concentration of N
therein. By increasing the concentration level of N as
20 such, the energy level of the conduction band of the
active layer is decreased, and the efficiency of
electron confinement in the active layer is improved.
Further, such an increase of the N content in the active
layer reduces the bandgap of the GaInNP mixed crystal
25 forming the active layer, while such a reduction of the

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1 bandgap of the active layer contributes to the reduction
of the oscillation wavelength of the laser diode.
Thereby, the laser diode successfully operates in the
visible wavelength including the 600 nm wavelength band.

5 Meanwhile, the inventor of the present
invention further discovered that the laser diode using
such a GaInNP active layer shows a poor efficiency when
the GaInNP active layer is grown directly on an optical
guide layer or cladding layer of AlGaInNP, in spite of
10 the fact that the quality of the GaInNP active layer
itself is improved substantially. The reason of this
unsatisfactory result is attributed to the existence of
Al in the underlying optical waveguide layer or cladding
layer, on which the GaInNP active layer is grown
15 epitaxially. It is believed that the poor crystal
quality of the surface of the AlGaInP layer is
transferred to the active layer grown thereon.

In order to avoid this problem, the present
invention proposes to separate the active layer of
20 GaInNP from the cladding layer or optical waveguide
layer of AlGaInP by using an intermediate layer of a
group III-V compound semiconductor material that is
substantially free from Al and N. By interposing such
an intermediate layer between the GaInNP active layer
25 and the cladding layer or optical waveguide layer of

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1 AlGaInP, the crystal quality of the active layer is
improved further, and the efficiency of laser
oscillation is improved substantially.

5 In order to avoid the unwanted increase of
laser oscillation wavelength caused as a result of
interaction of the carriers in the active layer with the
intermediate layer, it is preferable for form the
intermediate layer to have a thickness as small as
possible as compared with the thickness of the GaInNP
10 active layer but not smaller than a monoatomic layer
thickness, such that the carriers in the active layer do
not sense the effect of the potential barrier formed by
the intermediate layer. As long as the thickness of the
intermediate layer is sufficiently small, the
15 perturbation caused in the wavefunction of the carries
in the GaInNP active layer by the intermediate layer is
held minimum. Further, in order to avoid the formation
of a quantum well in the intermediate layer, it is
preferable that the material of the intermediate layer
20 forms the type-I heterojunction with the active layer
rather than the type-II heterojunction. In order to
improve the quality of the GaInNP active layer, it is
preferable that the group III-V compound semiconductor
material forming the intermediate layer is a binary or
25 ternary compound in the maximum. Further increase in

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1 the number of the constituent elements is
disadvantageous for securing the necessary quality for
the GaInNP active layer.

When the laser diode is to be constructed on a
5 GaAs substrate, the intermediate layer may be formed of
GaInP. By using GaInP, a lattice matching is guaranteed
with the cladding layer or optical waveguide layer, and
the accumulation of strain in the GaInNP active layer is
controlled relatively easily. Further, the use of
10 similar component elements for the intermediate layer
facilitates the growth of the necessary high-quality
crystal for the active layer. Alternatively, it is also
possible to use GaP for the intermediate layer, provided
that the thickness of the GaP intermediate layer is set
15 smaller than a critical thickness above which misfit
dislocations are formed. By using GaP for the
intermediate layer, the optical loss associated with the
optical absorption in the intermediate layer is
effectively suppressed as a result of the very large
20 bandgap of GaP.

When the laser diode is to be constructed on a
GaP substrate, on the other hand, the intermediate layer
may be formed of GaInP with a composition having a large
concentration for Ga. By choosing the composition of
25 the GaInP intermediate layer to have a high

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1 concentration of Ga, the bandgap of the intermediate
layer is increased and the lattice constant is reduced
in conformity with the GaP substrate having a very small
lattice constant. Thereby, the strain accumulated in
5 the GaInNP active layer is reduced also as compared with
the case of forming the laser diode on a GaAs substrate,
due to the reduced lattice constant of the GaInNP mixed
crystal caused as a result of admixing of N thereinto.
By using GaInP for the intermediate layer, it is further
10 possible to improve the quality of the active layer.

Further, the present invention proposes the
use of an MQW structure for the active layer of the
laser diode. Thereby, the MQW is formed as a result of
a repetitive and alternate stacking of a GaInNP quantum
15 well layer and a III-V barrier layer which may contain
Al, wherein the foregoing intermediate layer of GaInP is
interposed at the interface between the GaInNP quantum
well layer and the adjacent III-V barrier layer,
particularly at the interface between the GaInNP quantum
20 well layer and the underlying barrier layer.

As the GaInP intermediate layer does not have
a large bandgap comparable to that of the barrier
layers, the GaInP intermediate layer thus formed
adjacent to the GaInNP quantum well layer cannot form a
25 potential barrier defining a quantum well for the GaInNP

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1 quantum well layer. Rather, the GaInP intermediate
layer tends to form, together with the GaInNP quantum
well layer, an effectively integral quantum well having
an increased width. Thereby, it was discovered that the
5 upper intermediate layer, locating above the GaInNP
quantum well layer, can be omitted without reducing the
efficiency of optical emission substantially, although
such an omission of the upper intermediate layer induces
a loss of symmetry in the wavefunction of the carriers
10 confined in the effective quantum well. By omitting the
upper intermediate layer, the problem of increase of the
oscillation wavelength of the laser diode, caused as a
result of increase in the thickness of the effective
quantum well forming the active part of the laser diode,
15 is avoided successfully.

[FIRST EMBODIMENT]

In a first embodiment of the present
invention, a light-emitting semiconductor device having
20 an active layer of a group III-V compound semiconductor
material containing therein N and P as a group V element
is fabricated. More specifically, the active layer of
the first embodiment thus formed has a composition
represented as $\text{Ga}_{x_2}\text{In}_{1-x_2}\text{N}_{z_2}\text{P}_{1-z_2}$ ($0 \leq x_2 \leq 1$, $0 < z_2 < 1$).

25 FIGS.1 and 2 represent the surface of an

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1 AlGaInNP layer and a GaInNP layer formed on a GaAs
substrate as the active layer of the light-emitting
semiconductor device by an MOCVD process.

Referring to FIGS.1 and 2, it should be noted
5 that each of the AlGaInNP layer and the GaInNP layer was
formed with a thickness of about 1 μm , and the
deposition of the active layer was made on a crystal
surface of the GaAs substrate inclined in the $\langle 011 \rangle$
direction from the (100) surface by an angle of 15° .
10 The deposition was made by using TMG (tetramethyl
gallium), TMA (tetramethyl aluminum), TMI (tetramethyl
indium) and PH_3 as respective source of Ga, Al, In and P
together with a carrier gas of H_2 . Further, DMHy
(dimethylhydrazine) was used for the source of N. The
15 amount of N to be added to the active layer was
controlled such that any of the AlGaInNP active layer
and the GaInNP active layer achieves a lattice matching
with the GaAs substrate. More specifically, the
composition of the AlGaInNP active layer was set to
20 $\text{Al}_{0.1}\text{Ga}_{0.5}\text{In}_{0.5}\text{N}_{z2}\text{P}_{1-z2}$ ($0 < z2 < 1$), while the
composition of the GaInNP active layer was set to
 $\text{Ga}_{0.5}\text{In}_{0.5}\text{N}_{z1}\text{P}_{1-z1}$ ($0 < z1 < 1$).

From FIGS.1 and 2, it can be seen that the
AlGaInNP layer of FIG.1 shows a substantial roughness in
25 the surface morphology thereof, while the GaInNP layer

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1 of FIG.2 shows a mirror flat surface, in spite of the
fact that the growth of the GaInNP layer of FIG.2 was
conducted under a disadvantageous condition for
suppressing the surface roughness. More specifically,
5 the MOCVD process of growing the GaInNP layer was
conducted at a lower deposition temperature as compared
with the case of depositing the AlGaInNP layer of FIG.1
while supplying simultaneously a larger amount of DMHy.
In the growth of the GaInNP layer, the ratio of the flow
10 rate of DMHy to PH_3 (DMHy/PH_3) was set seventeen times
as large as the case of growing the AlGaInNP layer.

As a result of incorporation of such a large
amount of N without causing a deterioration in the
quality of the crystal, a shift of photoluminescent
15 spectrum of as much as 30 nm was observed in the longer
wavelength side was observed as compared with the case
in which the active layer contains no substantial amount
of N. This indicates the decrease of the bandgap energy
caused as a result of incorporation of N into the active
20 layer of GaInNP. In the present embodiment, it was
possible to introduce N successfully with a
concentration level of $1 \times 10^{20} \text{cm}^{-3}$, wherein the amount
of N thus introduced is equivalent to 0.5 % of the
entire group V elements.

25 In the case of using AlGaInNP for the active

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1 layer, there arises a problem of poor efficiency of
optical emission due to the deep level formed the mixed
crystal of AlGaInNP by Al. Further, the incorporation
of N further deteriorates the quality of the AlGaInNP
5 mixed crystal layer. The present invention successfully
avoids these problems by using GaInNP which is free from
Al.

[SECOND EMBODIMENT]

10 FIG.3 shows the construction of a
semiconductor layered structure 10 according to a second
embodiment of the present invention.

Referring to FIG.3, the semiconductor layered
structure 10 includes an SQW (single quantum well)
15 structure formed on a GaAs substrate 11 by an MOCVD
process, wherein the SQW structure is formed on a buffer
layer (not shown) of undoped GaAs formed on the GaAs
substrate 11 epitaxially with a thickness of about 0.2
 μm . The SQW structure, in turn, includes a barrier
20 layer 13 of undoped AlGaInP having a composition of
 $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.49}\text{In}_{0.51}\text{P}$, wherein the barrier layer 13 is
formed on the buffer layer epitaxially with a thickness
of about 0.2 μm . The barrier layer 13, in turn, is
covered by an intermediate layer 14 of undoped GaInP
25 having a composition of $\text{Ga}_{0.65}\text{In}_{0.35}\text{P}$ and formed

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1 epitaxially on the barrier layer 13 with a thickness of
about 1.2 nm, and an active layer 15 of undoped GaInNP
having a composition of $\text{Ga}_{0.65}\text{In}_{0.35}\text{N}_{0.008}\text{P}_{0.992}$ is
5 formed epitaxially on the intermediate layer 14 with a
thickness of about 35 nm.

The active layer 15, in turn, is covered by an
intermediate layer 16 of GaInP having a composition
similar to that the intermediate layer 14 with a
thickness of about 1.2 nm, and a cladding layer 17 of
10 AlGaInP having a composition similar to that of the
barrier layer 13 is formed epitaxially on the
intermediate layer 16 with a thickness of about 50 nm.

In the structure of FIG.3, it should be noted
that both the upper and lower intermediate layers 14 and
15 16 have the thickness of about 1.2 nm, while this
thickness corresponds to 2 molecular layers of GaInP.
Further, it should be noted that the principal surface
of the GaAs substrate 11, on which the structure of
FIG.3 is formed, is inclined in the $\langle 011 \rangle$ direction by
20 an angle of about 15° from the (100) surface. The
growth of the layers 13 - 17 is conducted by supplying
TMG, TMI, TMA, PH_3 and AsH_3 into a reaction chamber of
an MOCVD apparatus (not shown) with an appropriate
combination, together with a carrier gas of H_2 . During
25 the growth of the GaInNP quantum well layer 15, DMHy is

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1 added to the source gas as a source of N.

It should be noted that the layers 13 and 17
of AlGaInNP have a large bandgap and act as a barrier
layer sandwiching therebetween the active layer 15 of
5 GaInNP as a quantum well layer, wherein each of the
layers 13 and 17 having the foregoing composition of
 $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.49}\text{In}_{0.51}\text{P}$ achieves a lattice matching with
the GaAs substrate 11. On the other hand, the
intermediate layer 14 or 16 of the foregoing composition
10 $(\text{Ga}_{0.65}\text{In}_{0.35}\text{P})$ accumulates therein a tensile strain of
about 1% when used in combination with the GaAs
substrate 11. The active layer 15 of GaInNP has the
composition substantially identical with the composition
of the GaInP intermediate layer 14 or 16 except that the
15 active layer 15 further contains N. By increasing the
Ga content in the GaInNP mixed crystal of the active
layer 15, the amount of N that can be brought into the
active layer 15 is increased also. As noted above, the
active layer 15 has a composition represented as
20 $\text{Ga}_{0.65}\text{In}_{0.35}\text{N}_{0.008}\text{P}_{0.992}$.

FIG.4 shows the PL (photoluminescent) spectrum
obtained for the structure of FIG.3 in comparison with
the case in which the intermediate layers 14 and 16 are
omitted, wherein it should be noted that the curve (a)
25 of FIG.4 represents the PL spectrum of the structure of

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1 FIG.3, the curve (b) represents the case in which the
intermediate layers 14 and 16 are omitted from the
structure of FIG.3, while the curve (c) represents the
case in which a GaInP mixed crystal free from N is used
5 for the active layer 15 of FIG.3.

Referring to FIG.4, it can be seen that the PL
wavelength represented by the curve (a) is shifted in
the longer wavelength side (665 nm) with respect to the
curve (c) corresponding to the PL wavelength of 626 nm,
10 clearly demonstrating the effect of N that decreases the
bandgap of the GaInP mixed crystal. It should be noted
that the PL spectrum observed for the curve (a) is clear
and distinct, indicating that the quality of the GaInNP
mixed crystal used for the active layer 15 in the
15 structure of FIG.3 is excellent. In contrast, no PL
peak was observed when the intermediate layers 14 and 16
are eliminated.

The result of FIG.4 thus clearly demonstrates
the effect of the intermediate layers 14 and 16 for
20 improving the quality of the GaInNP mixed crystal used
for the active layer 15 in the structure of FIG.3.

In the SQW structure 10 of FIG.3, it is
further possible to tune the PL wavelength to the
shorter wavelength side by decreasing the thickness of
25 the active layer 15 such that there is formed a quantum

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1 well in the active layer 15. The structure of FIG.3 can
be used for various light-emitting devices and laser
diodes as will be described hereinafter with reference
to other embodiments.

5

[THIRD EMBODIMENT]

FIG.5 shows the construction of a stripe laser
diode 500 according to a third embodiment of the present
invention based on the layered structure 10 of FIG.3.

10

Referring to FIG.5, the laser diode 500 is
constructed on a substrate 501 of n-type GaAs having a
principal surface inclined in the $\langle 011 \rangle$ direction from
the (100) surface of GaAs by an angle of about 15° and
includes a buffer layer 502 of n-type GaAs formed
15 epitaxially on the foregoing principal surface of the
substrate 501, wherein the buffer layer 502 carries
thereon a lower cladding layer 503 of n-type AlGaInP
formed epitaxially with a composition of
($\text{Al}_{0.7}\text{Ga}_{0.3}$) $_{0.51}\text{In}_{0.49}\text{P}$, while the lower cladding layer
20 503 carries thereon an active layer 504 of undoped
GaInNP formed also epitaxially with a composition of
 $\text{Ga}_{0.51}\text{In}_{0.49}\text{N}_{0.01}\text{P}_{0.99}$, wherein an intermediate layer
510 of GaP is interposed between the lower cladding
layer 503 and the active layer 504. The intermediate
25 layer 510 thus formed has a thickness of about 2

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1 molecular layers, wherein the thickness is smaller than
a critical thickness above which there occurs a
formation of misfit dislocations in the intermediate
layer 510 as a result of lattice misfit with respect to
5 the GaAs substrate 501. Thereby, the intermediate layer
510 maintains an epitaxial relationship with the
underlying AlGaInP cladding layer 503.

On the active layer 504, an upper cladding
layer 505 of p-type AlGaInP is formed epitaxially with a
10 composition substantially identical with the composition
of the lower cladding layer 503 except for the
conductivity type, wherein another intermediate layer
511 of GaP is interposed between the active layer 504
and the upper cladding layer 505 with a thickness
15 smaller than the foregoing critical thickness. Thereby,
the intermediate layer 511 maintains an epitaxial
relationship with the underlying active layer 504.

Further, a contact layer 506 of p-type GaAs is
formed on the upper cladding layer 505, wherein the
20 contact layer 506 is covered by an insulating film 507
of SiO₂ and an upper, p-type electrode 508 of the
AuZn/Au structure is formed on the insulating film 507
in ohmic contact with the GaAs contact layer 506 via a
stripe opening formed in the insulating film 507.
25 Further, a lower, n-type electrode 509 of the AuGe/Ni/Au

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1 structure is formed on the bottom surface of the GaAs
substrate 501 in ohmic contact therewith.

It should be noted that the foregoing III-V
semiconductor layers 502 - 506 and 510, 511 are formed
5 typically by an MOCVD process or an MBE process, wherein
the upper and lower cladding layers 503 and 505 having
the composition described above achieve a lattice
matching with the GaAs substrate 501. Further, the
foregoing composition of the active layer 504 is the
10 composition that achieves a lattice matching with the
GaAs substrate. It should be noted that the admixing of
N into the active layer 504 causes a decrease in the
lattice constant, while the foregoing composition
compensates for such a decrease in the lattice constant
15 by increasing the Ga content.

By injecting holes into the active layer 504
from the top electrode 508 through the stripe opening
formed in the insulating film 507, there occurs a
stimulated emission in the central part of the active
20 layer 504 as a result of recombination of the holes thus
injected with the electrons that are injected from the
bottom electrode 509. In the laser diode 500 of the
present embodiment, it is of course possible to use a
current confinement structure other than the stripe
25 opening formed in the insulating film 507. Further, it

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1 is possible to use a strained active layer similar to
the case of the second embodiment for the active layer
504 in the laser diode 500, as long as the strained
active layer has a thickness smaller than the critical
5 thickness. By straining the active layer, the range
oscillation wavelength of the laser diode 500 is
increased, and the laser diode having such a
construction has an advantageous feature of degree of
freedom in tuning the laser oscillation wavelength by
10 inducing a quantum level in the active layer.

In the laser diode 500 of the present
embodiment, it is possible to use GaAs or InP for the
intermediate layer 510 or 511 in place of GaP. By using
GaAs for the intermediate layers 510 and 511, the
15 intermediate layers 510 and 511 achieve a perfect
lattice matching with the GaAs substrate 500. In the
case of using InP for the intermediate layers 510 and
511, on the other hand, it is necessary to set the
thickness of the intermediate layers 510 and 511 to be
20 smaller than a critical thickness above which there
occurs a development of misfit dislocations in the
intermediate layers 510 and 511. While it is also
possible to use other group III-V material for the
intermediate layers 510 and 511, it is desirable that
25 the intermediate layers 510 and 511 have a bandgap as

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1 large as possible for avoiding optical loss in the
active layer 504. The use of GaP noted above is
particularly advantageous in view of the excellent
quality of the GaInNP active layer 504 grown on the
5 intermediate layer 510.

[FOURTH EMBODIMENT]

FIG.6 shows the construction of a stripe laser
diode 600 according to a fourth embodiment of the
10 present invention.

Referring to FIG.6, the laser diode 600 is
constructed on a substrate 601 of n-type GaP carrying
thereon a buffer layer 602 of n-type GaP, wherein the
laser diode 600 includes a lower cladding layer 603 of
15 n-type AlP, and an optical waveguide layer 612 of
undoped AlGaP having a composition of $\text{Al}_{0.5}\text{Ga}_{0.5}\text{P}$ is
grown epitaxially on the lower cladding layer 603.
Further, the optical waveguide layer 612 is covered by
an intermediate layer of GaInP having a composition of
20 $\text{Ga}_{0.7}\text{In}_{0.3}\text{P}$ grown epitaxially on the optical waveguide
layer 612, and an active layer 604 of GaInNP having a
composition of $\text{Ga}_{0.7}\text{In}_{0.3}\text{N}_{0.01}\text{P}_{0.99}$ is formed
epitaxially on the underlying optical waveguide layer
612.

25 The active layer 604, in turn, is covered by

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1 an intermediate layer 611 grown epitaxially with a
composition substantially identical with the
intermediate layer 612, and the intermediate layer 611
is covered by an optical waveguide layer 613 grown
5 epitaxially on the intermediate layer 611 with a
composition substantially identical with the optical
waveguide layer 612. The optical waveguide layer 613,
in turn, is covered by an upper cladding layer 605 of p-
type AlP grown epitaxially on the optical waveguide
10 layer 613, and a contact layer 606 of n-type GaP is
formed further on the cladding layer 605.

The contact layer 606 is covered by an
insulating film 607 of SiO_2 , and a p-type electrode 608
provided on the insulating film 607 achieves an ohmic
15 contact with the GaP contact layer 606 via a stripe
opening formed in the insulating film 607. Further, an
n-type electrode 609 is formed on the bottom surface of
the GaP substrate 601 in ohmic contact therewith.

It should be noted that the foregoing III-V
20 semiconductor layers are grown on the GaP substrate 601
consecutively by an MOCVD process while using the
gaseous source materials noted before, and there is
formed a double heterostructure including the active
layer 604 and the upper and lower cladding layers 603
25 and 605 as the essential part of the laser diode 600.

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1 In the laser diode 600 having such a
construction, it should be noted that the active layer
604 of GaInNP is a material derived from GaInP, while
GaInP is the direct-transition type semiconductor
5 material having the largest bandgap. By introducing a
small amount of N, the GaInNP active layer 604 generally
achieves a lattice matching with the GaP substrate 601.

 In the laser diode 600 of FIG.6, the
intermediate layers 610 and 611 are formed of a GaInP
10 layer having a composition of $\text{Ga}_{0.7}\text{In}_{0.3}\text{P}$ and a
thickness of 2 molecular layers, while the intermediate
layers 610 and 611 may also be formed of GaP. In this
case, the intermediate layers 610 and 611 achieve an
ideal lattice matching with the GaP substrate 601.

15 FIG.7 shows the band diagram of the laser
diode 600 of FIG.6 for the part including the active
layer 604, intermediate layers 610 and 611 of
 $\text{Ga}_{0.7}\text{In}_{0.3}\text{P}$, optical waveguide layers 612 and 613 of
 $\text{Al}_{0.5}\text{Ga}_{0.5}\text{P}$, and cladding layers 603 and 605 of AlP.

20 Referring to FIG.7, it can be seen that the
conduction band E_c and the valence band E_v of the active
layer 604 is shifted in the lower energy side with
respect to the intermediate layer 610 or 611, causing a
staggered, type-II heterojunction interface between the
25 active layer 604 and the intermediate layer 610 or 611.

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1 Thereby, the efficiency of confinement of electrons in
the potential well formed in the conduction band E_c in
correspondence to the active layer 604 is improved.
Further, it should be noted that there is formed an
5 effective potential well for the holes in the valence
band E_v between the active layer 604 and the cladding
layer 603 or 605. Thus, an effective confinement of
holes in the active layer 604 is maintained, and the
efficiency of the laser diode 600 or the temperature
10 stability of the operational characteristic thereof is
improved substantially.

 In the band diagram of FIG.7, it should be
noted that the magnitude of the foregoing energy shift
of the active layer 604 is smaller in the valence band
15 E_v than in the conduction band E_c , due to the decrease
of the bandgap of GaInNP caused as a result of
incorporation of N thereinto.

 As the cladding layer 603 or 605 has a
refractive index substantially smaller than the
20 refractive index of the optical waveguide layers 612 and
613, there occurs also an effective optical confinement
of photons in the active layer 604 where the stimulated
emission takes place. The composition of the optical
waveguide layers 612 and 613 or the composition of the
25 cladding layers 603 and 605 is of course not limited to

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1 the foregoing combination but any other compositions may
be used as long as the composition of the optical
waveguide layers 612 and 613 is represented as $\text{Al}_{y1}\text{Ga}_{1-y1}\text{P}$ ($0 \leq y1 < 1$) and the composition of the cladding
5 layers 603 and 604 is represented as $\text{Al}_{y2}\text{Ga}_{1-y2}\text{P}$ ($0 \leq y1 < y2 \leq 1$).

In the laser diode 600 of FIG.6, the use of
GaInNP containing N and simultaneously a substantial
amount of Ga for the active layer 604 reduces the
10 lattice constant of the active layer 604 and hence the
compressive stress accumulated therein when combined
with the substrate 601 of GaP. Note that GaP forming
the substrate 601 has a very small lattice constant.
Thus, the laser diode 600 is advantageous for reducing
15 the laser oscillation wavelength. Further, due to the
reduced lattice misfit, the active layer 604 grown on
the Al-free intermediate layer 610 has an excellent
crystal quality and the efficiency of laser oscillation
is facilitated further.

20

[FIFTH EMBODIMENT]

FIG.8A shows the construction of a laser diode
700 according to a fifth embodiment of the present
invention.

25

Referring to FIG.8A, the laser diode 700 is

1 constructed on a substrate 701 of n-type GaAs having a
principal surface inclined in the $\langle 011 \rangle$ direction from
the (100) surface of GaAs by an angle of about 15° and
includes a buffer layer 702 of n-type GaAs formed
5 epitaxially on the foregoing principal surface of the
substrate 701, wherein the buffer layer 702 carries
thereon a lower cladding layer 703 of n-type AlGaInP
formed epitaxially with a composition of $(\text{Al}_{x_1}\text{Ga}_{1-x_1})\text{In}_{0.49}\text{P}$ ($0 < x_1 \leq 1$), while the lower cladding
10 layer 703 carries thereon an active layer having an MQW
structure shown in FIG.8B, wherein an optical waveguide
layer 712 of n-type AlGaInP having a composition of
 $(\text{Al}_{x_2}\text{Ga}_{1-x_2})\text{In}_{0.49}\text{P}$ ($0 < x_2 < x_1 \leq 1$) is interposed
between the lower cladding layer 703 and the MQW
15 structure constituting the active layer.

On the MQW active layer, there is formed an
upper cladding layer 705 of p-type AlGaInP epitaxially
with a composition substantially identical with the
composition of the lower cladding layer 703 except for
20 the conductivity type, and another optical waveguide
layer 713 of p-type AlGaInP is interposed between the
active layer and the upper cladding layer 705 with a
composition substantially identical with the composition
of the lower optical waveguide layer 713.

25 Further, a contact layer 706 of p-type GaAs is

1 formed on the upper cladding layer 705, wherein the
 contact layer 706 is covered by an insulating film 707
 of SiO_2 and an upper, p-type electrode 708 of the
 AuZn/Au structure is formed on the insulating film 707
5 in ohmic contact with the GaAs contact layer 706 via a
 stripe opening formed in the insulating film 707.
 Further, a lower, n-type electrode 709 of the AuGe/Ni/Au
 is formed on the bottom surface of the GaAs substrate
 701 in ohmic contact therewith.

10 The foregoing semiconductor layers may be
 formed by an MOCVD process with the gaseous source
 materials used in the preceding embodiments.

 FIG.8B shows the MQW structure forming the
 active layer of the laser diode 700.

15 Referring to FIG.8B, the active layer includes
 a repetitive stacking of the structural unit including a
 barrier layer 714 of undoped AlGaInP having a
 composition identical with the composition of the
 AlGaInP cladding layer 712 or 713 except for the
20 conductivity type and a quantum well layer 704 of an
 undoped GaInNP having a composition of
 $\text{Ga}_{0.51}\text{In}_{0.49}\text{N}_{0.01}\text{P}_{0.99}$ formed on the barrier layer 714,
 wherein there is interposed an intermediate layer 710,
 711 ... 715 of undoped GaInP having a composition of
25 $\text{Ga}_{0.51}\text{In}_{0.49}\text{P}$ at both upper and lower interface

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1 boundaries of each quantum well layer 704.

By interposing the undoped GaInP intermediate layers 710 and 711 at both upper and lower interface boundaries of the quantum well layer 704 constituting the MQW structure as such, an excellent quality is guaranteed for the quantum well layers 704 grown on such GaInP intermediate layers free from Al. In the embodiment of FIG.8B, it should be noted that a further intermediate layer 815 having the composition identical with the composition of the intermediate layer 710 or 711

[SIXTH EMBODIMENT]

FIG.9A shows the construction of a laser diode 800 according to a fifth embodiment of the present invention.

Referring to FIG.9A, the laser diode 800 is constructed on a substrate 801 of n-type GaAs having a principal surface inclined in the $\langle 011 \rangle$ direction from the (100) surface of GaAs by an angle of about 15° and includes a buffer layer 702 of n-type GaAs formed epitaxially on the foregoing principal surface of the substrate 801, wherein the buffer layer 802 carries thereon a lower cladding layer 803 of n-type AlGaInP formed epitaxially with a composition of $(\text{Al}_{x1}\text{Ga}_{1-x1})$

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1 x_1) $0.51\text{In}_{0.49}\text{P}$ ($0 < x_1 \leq 1$), while the lower cladding
layer 803 carries thereon an active layer having an MQW
structure shown in FIG.9B, wherein an optical waveguide
layer 812 of n-type AlGaInP having a composition of
5 $(\text{Al}_{x_2}\text{Ga}_{1-x_2})0.51\text{In}_{0.49}\text{P}$ ($0 < x_2 < x_1 \leq 1$) is interposed
between the lower cladding layer 803 and the MQW
structure constituting the active layer.

On the MQW active layer, there is formed an
upper cladding layer 805 of p-type AlGaInP epitaxially
10 with a composition substantially identical with the
composition of the lower cladding layer 803 except for
the conductivity type, and another optical waveguide
layer 813 of p-type AlGaInP is interposed between the
active layer and the upper cladding layer 805 with a
15 composition substantially identical with the composition
of the lower optical waveguide layer 813.

Further, a contact layer 806 of p-type GaAs is
formed on the upper cladding layer 805, wherein the
contact layer 806 is covered by an insulating film 807
20 of SiO_2 and an upper, p-type electrode 708 of the
 AuZn/Au structure is formed on the insulating film 807
in ohmic contact with the GaAs contact layer 806 via a
stripe opening formed in the insulating film 807.
Further, a lower, n-type electrode 809 of the AuGe/Ni/Au
25 is formed on the bottom surface of the GaAs substrate

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1 701 in ohmic contact therewith.

The foregoing semiconductor layers may be formed by an MOCVD process with the gaseous source materials used in the preceding embodiments.

5 FIG.9B shows the MQW structure forming the active layer of the laser diode 800.

Referring to FIG.9B, the active layer includes a repetitive stacking of the structural unit including a barrier layer 814 of undoped AlGaInP having a composition identical with the composition of the AlGaInP cladding layer 812 or 813 except for the conductivity type and a quantum well layer 804 of an undoped GaInNP having a composition of $\text{Ga}_{0.51}\text{In}_{0.49}\text{N}_{0.01}\text{P}_{0.99}$ formed on the barrier layer 814, wherein there is interposed an intermediate layer 810 of undoped GaInP having a composition of $\text{Ga}_{0.51}\text{In}_{0.49}\text{P}$ at a lower interface boundary of each quantum well layer 804.

By interposing the undoped GaInP intermediate layer 810 at both the lower interface boundary of each quantum well layer 804 constituting the MQW structure as such, an excellent quality is guaranteed for the quantum well layers 804 grown on such GaInP intermediate layer 810 free from Al.

FIG.10 shows the SIMS profile for a layered structure in which epitaxial layers of AlGaInP, GaInNP

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1 and AlGaInP are formed consecutively on a GaAs
substrate, without interposing an intermediate layer of
GaInP at the upper and lower interface boundaries of the
GaInNP epitaxial layer.

5 Referring to FIG.10, it can be seen that there
occurs a remarkable segregation of N at the top surface
of the AlGaInP epitaxial layer on which the GaInNP
epitaxial layer is to be formed, while no such a
segregation of N is observed at the top surface of the
10 GaInNP epitaxial layer on which the upper AlGaInP
epitaxial layer is to be formed. It is believed that
such a segregation of N at the top surface of the lower
AlGaInP layer is caused as a result of interaction of N
with the chemically reactive Al contained in the lower
15 AlGaInP epitaxial layer, while it is believed that such
an interaction causes the roughing in the top surface of
the lower AlGaInP epitaxial layer. It should be noted
that no such a roughing is observed for the top surface
of the GaInNP epitaxial layer, and the GaInNP epitaxial
20 layer thus grown has a mirror-flat top surface.

Thus, the MQW structure of FIG.9B, in which
the intermediate layer of undoped GaInP is interposed
only at the interface between the bottom surface of the
GaInNP quantum well layer and the underlying AlGaInP
25 barrier layer, is still effective for maintaining the

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1 excellent crystal quality for the GaInNP quantum well
layer. By omitting the upper intermediate layer
corresponding to the layer 711 of FIG.8B, the effective
thickness of the quantum well formed by the quantum well
5 layer 804 is reduced and the oscillation wavelength of
the laser diode 800 is reduced.

FIG.11 shows the band diagram of the quantum
well for the case of the laser diode 700 of FIG.7B while
FIG.12 shows the band diagram of the quantum well for
10 the laser diode 800 of FIG.8B.

Referring to FIG.11, it can be seen that the
quantum well layer 704 of GaInNP having a thickness d_a
forms a staggered, type-II heterojunction interface with
the intermediate layer 710 or 711 of GaInP, and there is
15 formed a potential well of electrons in the conduction
band E_c . As the thickness d_s of the intermediate layer
710 or 711 is very small corresponding to the thickness
of typically only 2 molecular layers, the effective
potential well which the electrons in the quantum well
20 layer 704 sense is relatively wide, having an effective
well width d_0 generally equal to the sum of the
thickness d_a and twice the thickness d_s ($d_a + 2d_s$), and
there is formed a quantum state E_e for the electrons at
a relatively low energy level in the conduction band E_c .
25 Further, there is formed a quantum state E_h for the

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1 holes in the valence band E_v at a relatively low energy
level corresponding to the foregoing effective width d_0
of the quantum well in the valence band E_v .

In the band diagram of FIG.11, It should be
5 noted that the quantum well layer 704 forms a potential
bump for the holes with respect to the intermediate
layers 710 and 711 as a result of the formation of the
staggered type-II heterojunction. Even in such a case,
there is formed a quantum well for the holes in the
10 valence band E_v in correspondence to the quantum well
layer 704 due to the potential barriers formed by the
barrier layers 714.

In the band diagram of FIG.12 corresponding to
the laser diode 800 of FIG.9B, on the other hand, it can
15 be seen that the band structure becomes asymmetric in
the direction perpendicular to the epitaxial layers of
the laser diode 800 due to the elimination of the upper
intermediate layer corresponding to the layer 711 of
FIG.11, and the quantum well formed in the conduction
20 band E_c has an effective width d_1 generally equal to the
sum of the thickness d_a and the thickness d_s ($d_a + d_s$),
wherein the effective width d_1 is smaller than the
effective width d_0 ($d_1 < d_0$). Associated therewith,
there is formed a quantum state E_e' for electrons at an
25 energy level higher than the energy level of the quantum

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1 state E_e . As the thickness d_a of the quantum well layer
804 with respect to the width d_1 of the potential well
formed in the band structure of FIG.12 is smaller than
in the case of FIG.11 ($d_a/d_1 > d_a/d_0$), the foregoing
5 asymmetry of the quantum well potential and associated
asymmetry of the wavefunction of the carriers confined
in the potential well is small, and the decrease of
overlap integral of the carrier probability amplitude
between the conduction band E_c and the valence band E_v
10 is minimized. In view of the fact that quantum states
are formed at relatively higher energy level in the case
of the laser oscillation at such a short wavelength, the
effect of asymmetric potential of the intermediate
layers does not appear significantly, and the problem of
15 deterioration of efficiency of carrier recombination and
associated decrease of efficiency of optical emission at
the active layer is successfully avoided.

[SEVENTH EMBODIMENT]

20 FIG.13 shows the construction of a vertical-
cavity laser diode 900 according to a seventh embodiment
of the present invention, wherein the laser diode 900
can be regarded as a modification of the laser diode 500
of the third embodiment described with reference to
25 FIG.5.

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1 Referring to FIG.13, the laser diode 900 is
constructed on a substrate 901 of n-type GaAs on which a
multilayer reflector structure 902 is formed as a result
of alternate and repetitive deposition of an n-type
5 AlInP epitaxial layer having a composition of
 $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ and an n-type GaInP epitaxial layer having a
composition of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$. In an example, the AlInP
layer and the GaInP layer constituting the multilayer
reflector structure 902 are doped by Se with a
10 concentration of about $3 \times 10^{17} \text{cm}^{-3}$ and have a thickness
of about 170 nm. The foregoing stacking structure of
the AlInP layer and the GaInP layer may be repeated
typically with 25 times.

On the multilayer reflector structure 902 thus
15 formed, there is formed a lower cladding layer 903 of n-
type AlGaInP epitaxially with a composition of
 $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.6}\text{P}$, and an intermediate layer 904a of
undoped GaInP having a composition of $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ is
formed further on the lower cladding layer 903
20 epitaxially with a thickness of typically 2 molecular
layers.

On the intermediate layer 904a thus formed,
there is formed an active layer 905 of undoped GaInNP
epitaxially with a composition of $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.01}\text{P}_{0.99}$,
25 wherein the active layer 905 carries thereon an

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1 intermediate layer 904b of undoped GaInP with a
composition of $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$, wherein the intermediate
layer 904b is formed with a thickness of typically 2
molecular layers.

5 On the intermediate layer 904b, there is
provided an upper cladding layer 906 of p-type AlGaInP
epitaxially with a composition substantially identical
with that of the lower cladding layer 903 except for the
conductivity type, wherein the upper cladding layer 906
10 is covered by another intermediate layer 907 of p-type
GaInP having a composition identical with the
composition of the intermediate layer 904a or 904b
except for the conductivity type.

On the intermediate layer 907, a contact layer
15 908 of p-type GaAs is formed epitaxially, wherein the
epitaxial layers above the multilayer reflector
structure 902 are subjected to a patterning process to
form a generally cylindrical structure having a diameter
of 10 μm for example and extending in the upward
20 direction from the top surface of the multilayer
reflector structure 902.

The side wall of the foregoing cylindrical
structure and further the exposed top surface of the
multilayer reflector structure 902 are covered by an
25 insulation film 910 of SiO_2 and a p-type electrode 911

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1 having the AuZn/Au structure is formed on the foregoing
side wall insulation film 910 so as to make an ohmic
contact with the top surface of the contact layer 908.

2 The p-type electrode 911 and the underlying
5 contact layer 908 are then patterned to form a circular
opening exposing the top surface of the intermediate
layer 907, and another multilayer reflector structure
909, formed of alternate stacking of an SiO_2 layer and a
 TiO_2 layer each having a thickness of corresponding to a
10 quarter wavelength of the laser oscillation wavelength,
for example, is provided on the contact layer 908 in
intimate contact with the exposed top surface of the
intermediate layer 907. The SiO_2 layer and the TiO_2
layer constituting the multilayer reflector structure
15 911 may be repeated about 6 times. Further, it should
be noted that an n-type electrode 912 having the
AuGe/Ni/Au structure is provided on the bottom surface
of the substrate 901 in ohmic contact therewith.

20 In the laser diode 900 of FIG.13, the upper
multilayer reflector structure 909 and the lower
multilayer reflector structure 902 form together a
vertical cavity and the laser diode 900 achieves
stimulated emission of optical radiation at the visible
wavelength band of 600 nm (0.6 μm). Thereby, the
25 optical beam thus produced in the active layer 905 is

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1 amplified as it is reflected back and forth between the
upper and lower multilayer reflector structures 909 and
902. The amplified optical beam is then emitted in the
upward direction as represented in FIG.13 by an arrow.

5 According to the laser diode 900 of the
present embodiment that uses the active layer 905
containing therein N as a group V element, it is
possible to produce a laser beam with the oscillation
wavelength of 600 nm band with high efficiency and
10 excellent temperature stability, similarly to the laser
diodes of the preceding embodiments. In the laser diode
900 of the present embodiment that uses the composition
of $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.01}\text{P}_{0.99}$ for the active layer 905, in
particular, the laser diode 900 produces the laser beam
15 at the wavelength of about 680 nm. It should be noted
that the active layer 905 of the foregoing composition,
characterized by a lattice constant smaller than the
lattice constant of GaAs, accumulates therein a tensile
stress.

20 In the laser diode 900 of the present
embodiment, it should be noted further that the use of
the intermediate layer 907 of InGaP containing therein
no substantial amount of N effectively suppresses the
roughing of the surface of the layer 907 on which the
25 upper multilayer reflection structure 909 is formed.

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1 Thereby, the problem of scattering of the optical beam
at such rough surface and associated decrease of the
efficiency of laser oscillation is avoided successfully.
In view of the bandgap energy of the GaInP intermediate
5 layer 907 larger than the bandgap energy of the GaInNP
active layer 905, there occurs no substantial absorption
in the optical radiation produced in the active layer
905.

10 [EIGHTH EMBODIMENT]

FIG.14 shows the construction of a laser diode
1000 according to an eighth embodiment of the present
invention, wherein those parts corresponding to the
parts described previously are designated by the same
15 reference numerals and the description thereof will be
omitted.

In the present embodiment, the multilayer
reflection structure 902 formed on the n-type GaAs
active layer 901 in the laser diode 900 is now replaced
20 by a multilayer reflection structure 1001, wherein the
multilayer reflection structure 1001 includes alternate
and repetitive stacking of an n-type AlGaInP epitaxial
layer having a composition of $(Al_aGa_{1-a})_{0.5}In_{0.5}P$ ($0 < a$
 ≤ 1) and another n-type AlGaInP epitaxial layer having a
25 composition of $(Al_bGa_{1-b})_{0.5}In_{0.5}P$ ($0 \leq b < a$), wherein

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1 each of the foregoing first and second AlGaInP epitaxial
layers is doped with Se and has a thickness
corresponding to a quarter wavelength of the oscillation
wavelength of the laser diode 1000.

5 In the laser diode 1000, it should further be
noted that the active layer 905 of the laser diode 900
of the previous embodiment is replaced by an active
layer 1002 of GaInNP, wherein the active layer 1002 has
a composition of $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.005}\text{P}_{0.995}$. The active
10 layer 905 is vertically sandwiched by the intermediate
layers 904a and 904b of undoped GaInP similarly to the
laser diode 900 of the previous embodiment.

The active layer 1002 thus covered by the
intermediate layer 904b is covered consecutively by a
15 layer 1003 of p-type InGaP to be described later and the
contact layer 908 of p-type GaAs, and an upper
multilayer reflector structure 1005 is formed on the
GaAs contact layer 908, wherein the multilayer reflector
structure 1005 contains therein alternate and repetitive
20 stacking of an undoped AlGaInP epitaxial layer having a
composition of $(\text{Al}_a\text{Ga}_{1-a})_{0.5}\text{In}_{0.5}\text{P}$ ($0 < a \leq 1$) and
another undoped AlGaInP epitaxial layer having a
composition of $(\text{Al}_b\text{Ga}_{1-b})_{0.5}\text{In}_{0.5}\text{P}$ ($0 \leq b < a$). It
should be noted that each of the foregoing first and
25 second AlGaInP epitaxial layers constituting the

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1 multilayer reflection structure 1005 has a thickness
corresponding to a quarter wavelength of the oscillation
wavelength of the laser diode 1000.

Further, the layered structure thus formed is
5 subjected to a patterning process to form a generally
cylindrical structure in the upper reflector structure
1005 such that the cylindrical structure extends in the
upward direction from the top surface of the contact
layer 908 with a diameter of about 5 μm for example, and
10 an ion implantation process of H^+ is conducted into the
exposed part of the contact layer 908 to form a high-
resistivity current confinement region 1006 of a ring-
shaped form, such that the current confinement region
1006 surrounds the cylindrical upper reflector structure
15 1005 with a separation therefrom at the top surface of
the GaAs contact layer 908 and such that the current
confinement region 1006 reaches the lower multilayer
reflector structure 1001 through the active layer 1002.
Further, the upper p-type electrode 911 is formed on the
20 top surface of the contact layer 908 in ohmic contact
therewith at the part where the current confinement
region 1006 is not formed. Similarly to the laser diode
900 of FIG.13, the GaAs substrate 901 carries the n-type
ohmic electrode 912 on the bottom surface thereof.

25 Similarly to the laser diode 900, there is

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1 formed a vertical cavity between the lower reflector
structure 1001 and the upper reflector structure 1005 in
the laser diode 1000 of FIG.14, and there occurs a
stimulated emission in the active layer 1002 as the
5 optical beam emitted as a result of the recombination of
carriers in the active layer 1002 is reflected back and
forth between the lower reflector structure 1001 and the
upper reflector structure 1005. The optical beam thus
amplified is emitted in the upward direction as
10 indicated by arrow in FIG.14. As a result of the
formation of the ring-shaped current confinement region
1006, the injection of the carriers occurs in the
limited area inside the current confinement region 1006,
and the emission of optical radiation as a result of
15 recombination of the carriers in the active layer 1002
occurs efficiently. In view of the composition of the
GaInNP active layer 1002 of $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.005}\text{P}_{0.995}$, the
oscillation wavelength of the laser diode 1000 of FIG.14
becomes about 650 nm. Similarly to the laser diodes of
20 the previous embodiments, the laser diode 1000 of the
present invention achieves an efficient confinement of
electrons in the active layer 1002 due to the shift of
the conduction band E_c in the lower energy direction
caused as a result of admixing of N thereto. See the
25 band diagram of FIG.7. Thereby, the laser diode 1000

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1 maintains the high efficiency of laser oscillation even
in the room temperature environment.

2 In the laser diode 1000, it should be noted
3 that the upper reflector structure 1005 can be formed
4 continuously in the same deposition apparatus without
5 interrupting the epitaxial process, contrary to the
6 laser diode 900 of FIG.13. In the case of the laser
7 diode 900 of FIG.13, it was necessary to interrupt the
8 epitaxial process and take out the device from the
9 deposition apparatus for dry etching, before resuming
10 the deposition of the upper multilayer reflector
11 structure 909. As the entire semiconductor layers are
12 formed in the same deposition apparatus without exposure
13 to the air, there occurs no formation of oxide on the
14 surface of the epitaxial layers and the upper multilayer
15 reflector structure 1005 forms the desired vertical
16 optical cavity, together with the lower multilayer
17 reflector structure 1001, with a predetermined cavity
18 length. Thereby, the fabrication process of the desired
19 vertical cavity laser diode is substantially facilitated
20 by using the structure of FIG.14.

21 In the laser diode 1000 of FIG.14, it should
22 be noted that the p-type GaInP layer 1003 has a
23 composition of $\text{Ga}_{0.6}\text{In}_{0.4}\text{P}$ and effectively reduces the
24 spike in the valence band formed in correspondence to
25

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1 the heterojunction interface between the cladding layer
906 of p-type AlGaInP and the contact layer 908 of p-
type GaAs. Thereby, the efficiency of hole injection
from the upper, p-type electrode 911 is facilitated
5 substantially. Further, the layer 1003 contributes to
the diffusion of the holes injected from the electrode
911 such that the holes are injected uniformly to the
cylindrical region of the semiconductor layered
structure defined by the ring-shaped current confinement
10 region 1006. As the GaInP intermediate layer 1003 has a
bandgap larger than the bandgap of the GaInNP active
layer 1002, there occurs no substantial absorption of
the optical beam produced by the recombination of
carriers taking place in the active layer 1002. As the
15 GaInP intermediate layer 1003 of the foregoing
composition does not achieve a lattice matching with the
GaAs substrate 901, the thickness of the layer 1003 is
set to about 10 nm such that the thickness of the layer
1003 does not exceed the critical thickness thereof.

20 In the laser diode 1000 of FIG.14, it should
further be noted that the contact layer 908 of p-type
GaAs absorbs the optical radiation emitted in the active
layer 1002 of GaInNP as a result of the carrier
recombination. Thus, the laser diode 1000 reduces the
25 thickness of the contact layer 908 to about 5 nm so that

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1 the effect of the optical absorption is minimized.

Similarly to the laser diode of the previous
embodiments, the laser diode 1000 of the present
embodiment also avoids the deterioration of crystal
5 quality or laser oscillation efficiency, by sandwiching
the GaInNP active layer 1002 by the GaInP intermediate
layers 904a and 904b.

[NINTH EMBODIMENT]

10 FIG.15 shows the construction of a vertical-
cavity laser diode 1100 according to a ninth embodiment
of the present invention, wherein those parts
corresponding to the parts described previously are
designated by the same reference numerals and the
15 description thereof will be omitted.

Referring to FIG.15, the laser diode 1100 has
a construction similar to that of the laser diode 1000
of FIG.14, except that the lower multilayer reflector
structure 1001 is replaced with a multilayer reflector
20 structure 1101 including therein alternate and
repetitive stacking of a low refractive epitaxial layer
of n-type and a high refractive epitaxial layer of n-
type each having a thickness corresponding to a quarter-
wavelength of the laser oscillation wavelength. It
25 should be noted that the low refractive layer is

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1 typically formed of $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ doped with Se, while the
high refractive layer is formed of a stacking of a Se-
doped $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ having a thickness of 4.5 nm a Se-
doped $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ having a thickness of 1.5 nm. The
5 foregoing high refractive epitaxial layer and the low
refractive epitaxial layer are repeated about 25 times
and form a super-lattice structure that constitutes the
lower reflector structure 1101. Thereby, the super-
lattice structure thus formed has an effective bandgap
10 generally corresponding to that of the AlGaInP mixed
crystal having a composition of $(\text{Al}_{0.1}\text{Ga}_{0.9})_{0.5}\text{In}_{0.5}\text{P}$.
Further, the laser diode 1100 of the present embodiment
uses an upper reflector structure 1105 in place of the
upper reflector structure 1005 of FIG.14, wherein it
15 should be noted that the upper reflector structure 1105
has a similar super-lattice structure except that the
epitaxial layers are not doped and that the high
refractive epitaxial layer and the low refractive
epitaxial layer are repeated 20 times.

20 Further, the laser diode 1100 uses an active
layer 1103 having an MQW structure in combination with
an n-type lower cladding layer 1102 of AlGaInP and a p-
type upper cladding layer 1104 both having a composition
of $\text{Al}_{0.5}\text{Ga}_{0.5}\text{P}$. Further, the GaInP layer 1003 used in
25 the laser diode 1000 of FIG.14 is replaced with the

1 GaInP layer 907 of the composition $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$, which is
used in the laser diode 900 of FIG.13.

FIG.16A shows the band structure of the lower
multilayer reflector structure 1101 taken in the
5 direction perpendicular to the epitaxial layers.

Referring to FIG.16A, it can be seen that the
multilayer reflector structure 1101 includes an
alternate repetition of a low refractive layer 1201 of
AlInP doped with Se and having the composition of
10 $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ and a high refractive layer 1202 provided
adjacent to the layer 1201, wherein the high refractive
layer 1202 is formed of a stacking of a GaInP layer
having the composition of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ and doped with Se
and an AlInP layer doped also with Se and having the
15 composition of $\text{Al}_{0.5}\text{In}_{0.5}\text{P}$ as noted previously. The
GaInP layer has a thickness of 4.5 nm in the high
refractive layer 1202 while the AlInP has a thickness of
1.5 nm in the high refractive layer 1202. A similar
band structure exists also in the upper multilayer
20 reflector structure 1105 except that the epitaxial
layers therein are substantially free from doping.

FIG.16B shows the band diagram of the MQW
structure forming the active layer 1103.

Referring to FIG.16B, the active layer 1103
25 includes alternate and repetitive stacking of a barrier

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1 layer 1205 of undoped AlInP having the composition of
Al_{0.5}In_{0.5}P and a quantum well layer 1204 of undoped
GaInNP having the composition of Ga_{0.5}In_{0.5}N_{0.005}P_{0.995},
wherein each of the barrier layer 1205 and the quantum
5 well layer 1204 has a thickness of 3 nm. Further, it
should be noted that there is interposed an intermediate
layer 1203 of undoped GaInP having the composition of
Ga_{0.5}In_{0.5}P at the upper and lower surfaces of each
quantum well layer 1204 in direct and intimate contact
10 therewith, such that the intermediate layers 1203
sandwich therebetween the quantum well layer 1204.

As can be seen in the band diagram of FIG.16B,
the conduction band Ec and the valence band Ev of the
GaInNP quantum well layer 1204 are shifted in the lower
15 energy direction with respect to those of the GaInP
intermediate layer 1203 as a result of the admixing of N
as a group V element, wherein the quantum well layer
1204 having such a composition produces an optical
radiation with the wavelength of 650 nm. As a result of
20 the shifting of the conduction band Ec for the quantum
well layer 1204, there occurs an excellent confinement
of electrons in the quantum well layer and the problem
of overflowing of thermally excited electrons from the
quantum well layer is successfully suppressed. Thereby,
25 the laser diode of the present embodiment provides the

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1 feature of efficient layer oscillation even in the room
temperature environment.

By using the intermediate layers 1203 in the
MQW structure of the active layer 1103, epitaxial growth
5 of a high-quality crystal layer is guaranteed for the
quantum well layer 1204 that contains N as the group V
element, even when the quantum well layer 1204 is used
in combination with the barrier layer 1205 that contains
Al. Further, the quantum well layer 1204 thus grown on
10 the Al-free intermediate layer 1203 has a smooth,
mirror-flat surface.

It should be noted that the foregoing
formation of the super-lattice structure in the
multilayer reflector structure 1101 or 1105 or the
15 formation of the MQW structure 1103 is achieved easily
by interrupting or switching the supply of the gaseous
source materials, while such a interruption or switching
of the source material is conducted by merely
controlling the valve used for supplying the gaseous
20 source material in a MOCVD apparatus or the shutter of
an MBE apparatus.

[TENTH EMBODIMENT]

FIG.17 shows the construction of an optical
25 disk drive 1300 according to a tenth embodiment of the

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1 present invention.

Referring to FIG.17, the optical disk drive 1300 includes a spindle motor 1309 rotating an optical disk 1308 mounted thereon detachably, wherein the
5 optical disk drive 1300 further includes a vertical-cavity laser diode 1301 that emits an optical beam in the wavelength band of 0.6 μm in the direction perpendicular to the epitaxial layers forming the laser diode 1301. The laser beam thus emitted is collimated
10 by a lens 1302 and is directed to a scanning mirror 1304 via an optical beam splitter 1303. The scanning mirror 1304 in turn focuses the laser beam supplied thereto at a desired location of the optical disk 1308 via an objective lens 1305. By driving the scanning mirror
15 1304, the optical beam spot of the laser beam scans over the recording surface of the optical disk 1308.

Further, the optical disk drive 1300 includes a photodetector 1307 for detecting the laser beam reflected by the optical disk 1308, wherein the laser
20 beam reflected by the optical disk 1308 is directed to the photodetector 1307 via the optical beam splitter 1303 and a lens 1306.

In the optical disk drive 1300 of the foregoing construction, it is possible to achieve a
25 reliable read/write operation by using the laser diode

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1 of any of the preceding embodiments for the laser diode
1301, without using a cooling system or temperature
regulation system.

5 [ELEVENTH EMBODIMENT]

FIG.18 shows the construction of an optical
transmission system 1400 according to an eleventh
embodiment of the present invention.

Referring to FIG.18, the optical transmission
10 system 1400 of the present embodiment includes an
optical transmitter 1401, wherein the optical
transmitter 1401 includes a drive circuit 1402 supplied
with an electrical signal and a vertical-cavity laser
diode 1403, wherein the vertical-cavity laser diode 1403
15 is driven by a driving signal produced by the drive
circuit 1402 in response to the electrical signal
supplied to the drive circuit 1402. Further, it should
be noted that the laser diode 1403 is coupled optically
to a plastic optical fiber 1404 having a transmission
20 band of 0.6 μm and the optical beam emitted by the laser
diode 1403 is effectively injected into the core of the
optical fiber 1404.

In the optical transmission system 1400 of the
present embodiment, it should be noted the optical
25 transmitter 1401 operates efficiently and with

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1 reliability by using any of the vertical cavity laser
diodes 900 - 1100 described with reference to FIGS.13 -
15. The use of the laser diodes 900 - 1100 of the
present invention is particularly preferably in view of
5 the oscillation wavelength thereof of 0.6 μm band
coincident to the transmission band of a plastic optical
fiber.

[TWELFTH EMBODIMENT]

10 As explained previously with reference to the
band diagram of FIG.7 or with reference to the band
diagrams of FIGS.11 and 12, the use of the GaInNP layer
for the active layer in combination with the
intermediate layer of GaInP causes a shifting in energy
15 for the conduction band and valence band of the GaInNP
active layer in the lower energy direction with respect
to the intermediate layer, and there tends to appear a
staggered, type-II heterojunction at the interface
between the intermediate layer and the active layer as
20 represented in FIG.19A, which is similar to the band
diagram of FIG.7.

While such a type-II heterojunction may be
useful for confining electrons in the active layer, such
a structure is not suitable for confinement of holes in
25 the active layer. In fact, the holes are not confined

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1 in the active layer as long as the staggered band
structure of FIG.19A is used, and it has been necessary
to provide an outer potential well outside the
intermediate layer of GaInP in the laser diode of
5 previous embodiments for achieving the confinement of
the holes necessary for the operation of the laser
diode. In such a case, however, the overlap integral of
the carrier wavefunction between the conduction band and
the valence band is tend to be reduced and the
10 efficiency of optical radiation of the laser diode is
tend to be deteriorated. It is desired that the carrier
confinement occurs in the active layer similarly for the
electrons and for the holes.

On the other hand, it is known that the band
15 structure of a III-V compound semiconductor material
changes when a stress is applied as represented in
FIG.19B or FIG.19C, wherein it should be noted that
FIG.19B represents the case in which a compressive
stress is applied to the material system in which a
20 GaInNP layer is sandwiched by a pair of GaInP layers,
while FIG.19C represents the case in which a tensile
stress is applied to the same material system. In the
band structure of FIG.19B, it can be seen that the
valence band E_v becomes substantially flat at the
25 heterojunction interface between the GaInP layer and the

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1 GaInNP layer while simultaneously maintaining a large
band discontinuity in the conduction band E_c in
correspondence to the foregoing heterojunction
interface. In the case of FIG.19C, on the other hand,
5 the magnitude of band discontinuity at the conduction
band E_c is reduced while the bump of the conduction band
 E_v is not eliminated.

In the laser diode, it is preferable to form a
type-I heterojunction at the interface between the
10 GaInNP active layer and the adjacent intermediate layers
of GaInP as represented in FIG.19D, wherein it should be
noted that the magnitude of shift of the conduction band
 E_c or valence band E_v can be evaluated by the strong
coupling theory of Harrison according to the
15 relationship

$$\Delta E_c = -2a\{(c_{11}-c_{12})/c_{11}\}\epsilon, \text{ and}$$

$$\Delta E_c = 2a'\{(c_{11}-c_{12})/c_{11}\}\epsilon + b\{(c_{11}+c_{12})/c_{11}\}\epsilon,$$

20 wherein c_{11} and c_{12} represent the lattice constant, a
represents the hydrostatic deformation potential of the
conduction band E_c , a' represents the hydrostatic
deformation potential of the valence band E_v , b
represents an axial deformation potential, while ϵ
25 represents a lattice strain. About the strong coupling

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1 theory of Harrison, reference should be made to Appl.
Phys. Lett. vol.60, no.5, pp.630-632, 1992.

FIG.20A shows the calculated change of the
valence band energy E_v and the conduction band energy E_c
5 under a compressive stress by decreasing the Ga content
 x below the lattice matching composition of $x=0.52$,
while FIG.20B shows the change of the valence band
energy E_v and the conduction band energy E_c under a
tensile stress. In the calculation of FIG.20B, the Ga
10 content x is increased beyond the foregoing lattice
matching composition.

The result of FIGS.20A and 20B indicates that
the bottom edge of the valence band E_v can be shifted in
the direction of higher energy side by increasing the Ga
15 content x in the GaInNP active layer. By adjusting the
amount x of Ga in the GaInNP active layer, it is
possible to eliminate the foregoing bump of the valence
band as represented in the band diagram of FIG.19D. In
FIG.19D, it should be noted that ΔE_v represents the
20 shift of the valence band energy E_v caused as a result
of change in the Ga content x in the GaInNP mixed
crystal, ΔE_{strain} represents the foregoing shift of the
valence band energy E_v caused as a strain in the GaInNP
mixed crystal forming the active layer, and ΔE_N
25 represents shift of the valence band energy E_v caused as

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1 a result of incorporation of N in to the GaInNP mixed
crystal. In order to achieve the foregoing elimination
of the valence band E_v in the GaInNP active layer, it is
necessary that the foregoing relationship holds between
5 the quantities E_N , ΔE_{strain} and ΔE_v as

$$\Delta E_N + \Delta E_{\text{strain}} + \Delta E_v > 0.$$

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The band diagram of FIG.19D represents the so-
10 called type-I heterojunction, which is advantageous for
efficient recombination of carriers, as both the
electrons and the holes are accumulated in respective
potential wells formed in the conduction band E_c or the
valence band E_v of the GaInNP active layer.

15 In FIG.20B, it can be seen that the increase
of the Ga content x in the GaInNP layer also causes an
increase in the conduction band energy E_c . However, the
magnitude of shift of the conduction band energy E_c ,
caused as a result of increase of the Ga content x
20 beyond the lattice matching composition, is
substantially smaller than the foregoing shift ΔE_{strain} ,
and the effective confinement of the electrons in the
conduction band is maintained even when the GaInNP
active layer is thus strained by a tensile stress.

25 FIG.19E shows another principle of modifying

1 the type-II heterojunction of FIG.19A to a type-I
heterojunction, wherein FIG.19E achieves the desired
modification of the band structure by introducing a p-
type dopant into the active layer of GaInNP. As a
5 result of such a p-type doping, there occurs a relative
shift of the Fermi level E_{fp} of the GaInNP active layer
in the lower energy side with respect to the conduction
band E_c or the valence band E_v thereof, while such a
relative shift of the Fermi level E_{fp} in the lower
10 energy side inside the GaInNP active layer causes, in
turn, an overall shifting of the conduction band E_c and
the valence band E_v of the active layer in the higher
energy side with respect to the conduction band E_c or
the valence band E_v of the adjacent GaInP optical
15 waveguide layer or cladding layer. In the equilibrium
state, it should be noted that the Fermi energy level
 E_{fp} of the GaInNP active layer has to coincide with the
Fermi energy level of the adjacent GaInP optical
waveguide layer or cladding layer.

20 As a result of such an overall shifting of the
band diagram of the GaInNP active layer with respect to
the GaInP optical waveguide layer or cladding layer, the
type-II heterojunction of FIG.19A is successfully
modified to the type-I heterojunction represented in
25 FIG.19E. Thereby, an excellent carrier confinement is

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1 guaranteed in the GaInNP active layer for both the
electrons and holes, and the efficiency of the laser
diode is improved.

5 A similar relative shifting of the Fermi
energy level occurs also when the GaInP intermediate
layer is doped with an n-type dopant. In the case of
doping the GaInP intermediate layer by a p-type dopant,
there occurs a shifting of the Fermi energy level E_{fn} in
the higher energy side with respect to the conduction
10 band E_c and the valence band E_v , and the band structure
of the GaInP intermediate layer thus doped is shifted as
a whole in the lower energy side with respect to the
GaInNP active layer, which is now free from doping.
Thereby, there appears a band structure represented in
15 FIG.19F, wherein there is formed a type-I heterojunction
at the interface between the n-type GaInP intermediate
layer and the undoped GaInNP active layer. In the
example of FIG.19F, the opposite intermediate layer of
GaInP is not doped, and there is formed a type-II
20 heterojunction at the interface between the active layer
of GaInNP and the intermediate layer of undoped GaInP
similarly to the case of FIG.19A.

FIG.21 shows the construction of a SCH-type
laser diode 1500 according to a twelfth embodiment of
25 the present invention.

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1 Referring to FIG.21, the laser diode 1500 is
constructed on a substrate 1501 of n-type GaAs covered
by a buffer layer 1502 of n-type GaAs grown epitaxially
on the substrate 1501 and includes a lower cladding
5 layer 1503 of n-type AlGaInP and a lower optical guide
layer 1504 of undoped AlGaInP, wherein the lower
cladding layer 1503 and the lower optical waveguide
layer 1504 are grown epitaxially and consecutively on
the buffer layer 1502 by an MOCVD process with
10 respective thicknesses of 1 μm and 0.1 μm and respective
compositions of $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ and
 $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$.

On the lower optical waveguide layer 1504,
there is formed a lower intermediate layer 1505a of
15 undoped GaInP having a composition of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$ with a
thickness of about 2nm, and an active layer 1506 of
undoped GaInNP having a composition of
 $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.01}\text{P}_{0.99}$ is formed further on the lower
intermediate layer 1505a with a thickness of about 30
20 nm. Further, an upper intermediate layer 1505b of
undoped GaInP having a composition substantially the
same as the composition of the lower intermediate layer
1505a is formed epitaxially on the active layer 1506
with a thickness of about 2 nm, and an upper optical
25 waveguide layer 1507 of undoped AlGaInP having a

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1 composition of $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$ is further formed
epitaxially on the upper intermediate layer 1505a with a
thickness of about 0.1 μm .

Further, an upper cladding layer 1508 of n-
5 type AlGaInP having a composition of
 $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ is grown epitaxially on the upper
optical waveguide layer 1507 with a thickness of about 1
 μm , and a contact layer 1510 of p-type GaAs is formed
epitaxially on the upper cladding layer 1508 with a
10 thickness of about 0.5 nm, with an anti-spike layer 1509
of p-type GaInP having a composition of $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$
interposed between the upper cladding layer 1508 and the
contact layer 1510 with a thickness of about 50 nm.

The contact layer 1510 is patterned to form a
15 stripe pattern extending in the longitudinal direction
of the laser diode 1500 on the anti-spike layer 1509,
while the anti-spike layer 1509 is covered, at both
lateral sides of the contact layer 1510, by a pair of
insulation patterns 1511 of SiO_2 . Further, a p-type
20 electrode 1512 is deposited on the insulation patterns
1511 including the exposed contact layer 1510, wherein
the electrode 1512 achieves an ohmic contact with the
contact layer 1510. Further, an n-type electrode 1513
is formed on the bottom surface of the substrate 1501 in
25 ohmic contact therewith.

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1 In the laser diode 1500 of the present
embodiment, it should be noted that the active layer
1506 contains N and the efficiency of electron
confinement in the potential well formed in the
5 conduction band in correspondence to the active layer
1506 is improved substantially. It should be noted that
there is formed a band discontinuity of about 80 meV in
the bottom edge of the conduction band at the interface
between the active layer 1506 and the adjacent
10 intermediate layer 1505a or 1505b as a result of
incorporation of N into the active layer 1506.

On the other hand, such a mere incorporation
of N into the active layer 1506 leads to the formation
of the type-II band structure shown in FIG.19A at the
15 heterojunction interface between the active layer 1506
and the adjacent intermediate layer 1505a or 1505b as
noted previously. Thus, the present invention modifies
the Ga content in the active layer 1506 such that the
active layer 1506 is no longer satisfies the lattice
20 matching with respect to the GaAs substrate 1501. More
specifically, the foregoing composition of
 $\text{Ga}_{0.6}\text{In}_{0.4}\text{N}_{0.01}\text{P}_{0.99}$ for the GaInNP active layer 1506
causes an accumulation of tensile strain of about 0.6%
therein, and there occurs a shifting in the valence band
25 energy E_v of the GaInNP active layer 1506 in the higher

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$$15 \quad \Delta E_{N^+} \Delta E_{\text{strain}} + \Delta E_v > 0,$$

In the embodiment of FIG.21, it should be noted that the upper and lower intermediate layers 1505a and 1505b have a lattice matching composition with respect to the GaAs substrate 1501. By using the intermediate layers 1505a and 1505b, which are free from

1 N, between the N-containing active layer 1506 and the
optical waveguide layer 1504 or 1507 that contains Al,
similarly to the laser diodes of the preceding
embodiments, the active layer 1506 has an excellent
5 quality and the efficiency of the laser oscillation is
improved further.

[THIRTEENTH EMBODIMENT]

FIG.22 shows the construction of an SCH laser
10 diode 1600 according to a thirteenth embodiment of the
present invention, wherein those parts corresponding to
the parts described previously are designated by the
same reference numerals and the description thereof will
be omitted.

15 Referring to FIG.22, the laser diode 1600 has
a construction similar to that of the laser diode 1500
except that the active layer 1506 of the laser diode
1500 is now replaced by an active layer 1601 of GaInNP
having a composition of $\text{Ga}_{0.45}\text{In}_{0.55}\text{N}_{0.01}\text{P}_{0.99}$. It
20 should be noted that the foregoing composition of the
active layer 1601 is not a lattice matching composition
with respect to the GaAs substrate 1501 and there is
introduced a compressive strain of about 0.5%.

In response to the introduction of N, there
25 occurs a decrease in the bandgap in the GaInNP active

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1 layer 1601 of as much as about 150 meV, wherein it
should be noted that there further occurs a shift in the
bottom edge of the valence band E_v in the lower energy
side with the magnitude of about 18 meV, similarly to
5 the embodiment of FIG.21. Thereby, there is formed a
type-II heterojunction represented in FIG.19A at the
interface between the active layer 1601 and the adjacent
intermediate layer 1505a or 1505b, also similarly to the
embodiment of FIG.21.

10 In the present embodiment, on the other hand,
the foregoing shift of the bottom edge of the valence
band E_v is successfully compensated for by the
compressive strain of about 0.5%. It should be noted
that the foregoing compressive strain causes a shift in
15 the bottom edge of the valence band with a magnitude of
about 33 meV in the higher energy side at the foregoing
composition of $\text{Ga}_{0.45}\text{In}_{0.55}\text{P}$, as compared with the GaInP
mixed crystal of the lattice matching composition of
 $\text{Ga}_{0.5}\text{In}_{0.5}\text{P}$. See the relationship of FIG.20A. Thereby,
20 the valence band E_v of the GaInNP active layer 1601 is
located at the higher energy side as compared with the
valence band E_v of the adjacent intermediate layer 1505a
or 1505b.

As the conduction band E_c of the active layer
25 1601 is located at the lower energy side with respect to

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1 the conduction band of the intermediate layer 1505a or
1505b, the type-II heterojunction of FIG.19A is
successfully modified to the type-I as represented in
FIG.19D, and the laser diode 1600 oscillates with
5 excellent efficiency and stability.

[FOURTEENTH EMBODIMENT]

FIG.23 shows the construction of a SCH laser
diode 1700 according to a fourteenth embodiment of the
10 present invention, wherein those parts corresponding to
the parts described previously are designated by the
same reference numerals and the description thereof will
be omitted.

Referring to FIG.23, the laser diode 1700 has
15 a construction similar to that of the laser diode 1500
except that the active layer 1506 of the laser diode
1500 is now replaced by an active layer 1701 of GaInNP
having a lattice matching composition of
 $\text{Ga}_{0.5}\text{In}_{0.5}\text{N}_{0.01}\text{P}_{0.99}$ and doped to the p-type by Mg with
20 a concentration level of $2 \times 10^{18} \text{cm}^{-3}$. The active layer
1701 may have a thickness of about 30 nm.

In response to the introduction of N, there
occurs a decrease in the bandgap in the GaInNP active
layer 1701 of as much as about 150 meV similarly to the
25 preceding embodiments. Further, the energy level of the

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1 valence band is shifted in the lower energy side also in
the active layer 1701, and there is formed a type-II
heterojunction at the interface between the GaInNP
active layer 1701 and the adjacent intermediate layer
5 1505a and 1505b.

In the present embodiment, on the other hand,
the foregoing shift of the bottom edge of the valence
band E_v is successfully compensated for by the overall
shift of the band structure in the higher energy side
10 caused for the GaInNP active layer 1701 as a result of
doping of the same to the p-type, as explained before
with reference to FIG.19E. As a result of such a
shifting of the overall band structure including the
conduction band E_c and the valence band E_v , the valence
15 band E_v of the GaInNP active layer 1701 is located at
the higher energy side as compared with the valence band
 E_v of the adjacent intermediate layer 1505a or 1505b.

As the conduction band E_c of the active layer
1701 is located still at the lower energy side with
20 respect to the conduction band of the intermediate layer
1505a or 1505b, even after the doping of the active
layer 1701 to the p-type, the type-II heterojunction of
FIG.19A is successfully modified to the type-I as
represented in FIG.19E, and the laser diode 1700
25 oscillates with excellent efficiency and stability.

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[FIFTEENTH EMBODIMENT]

FIG.24 shows the construction of a SCH laser diode 1800 according to a fourteenth embodiment of the present invention, wherein those parts corresponding to the parts described previously are designated by the same reference numerals and the description thereof will be omitted.

Referring to FIG.24, the laser diode 1800 has a construction similar to that of the laser diode 1500 except that the lower intermediate layer 1505a of the laser diode 1500 is replaced by an intermediate layer 1801 of n-type GaInP having a thickness of 2 nm and doped with Se to a concentration level of $5 \times 10^{18} \text{cm}^{-3}$ and that the active layer 1506 is replaced by an active layer 1801 of undoped GaInNP having a lattice matching composition of $\text{Ga}_{0.5}\text{In}_{0.5}\text{N}_{0.01}\text{P}_{0.99}$. The active layer 1802 may have a thickness of 30 nm.

In the laser diode 1800, too, there occurs a decrease in the bandgap in the GaInNP active layer 1801 in response to the introduction of N thereto, of as much as about 150 meV similarly to the preceding embodiments. Further, the energy level of the valence band is shifted in the lower energy side also in the active layer 1802, and there is formed a type-II heterojunction at the

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1 interface between the GaInNP active layer 1802 and the
adjacent intermediate layer 1505b.

In the present embodiment, on the other hand,
the lower intermediate layer 1801 is doped to the n-type
5 and the band structure of the intermediate layer 1801 is
shifted in the lower energy side with respect to the
undoped GaInNP active layer 1802, as explained already
with reference to FIG.19F.

Thereby, there is formed a type-I
10 heterojunction at the interface between the active layer
1802 and the underlying intermediate layer 1801, and
there occurs an effective blocking of holes injected
from the p-type electrode 1512 and escaping to the n-
type GaAs substrate 1501.

15 Thus, the laser diode 1800 of the present
embodiment is also effective for increasing the
efficiency of carrier recombination taking place in the
active layer 1802.

20 [SIXTEENTH EMBODIMENT]

Next, description will be made on an improved
fabrication process of a group III-V semiconductor
device such as a laser diode that includes therein a
III-V semiconductor layer containing N as a group V
25 element according to a sixteenth embodiment of the

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1 present invention.

2 In the foregoing embodiments described
3 heretofore, the epitaxial growth of the active layer of
4 the group III-V compound semiconductor material
5 containing N as a group V element has been achieved by
6 an MOCVD process that uses DMHy as the source of N. As
7 such a III-V system containing N as a group V element
8 includes a large immiscibility gap therein, the
9 epitaxial growth of such a GaInNP active layer is by no
10 means an obvious matter.

11 While the inventor of the present invention
12 has previously found a successful way to grow such an
13 epitaxial layer with controlled amount of N therein, as
14 described in the United States patent application
15 08/917,141 which is incorporated herein as reference,
16 there is still a room for improvement.

17 In the growth of a semiconductor layer on an
18 underlying layer or substrate, the nucleation process on
19 the underlying layer is generally an important factor.
20 In the case of the epitaxial growth of a III-V mixed
21 crystal layer that includes a large immiscibility gap
22 therein, the nucleation process is believed to be a
23 critical factor for the successful epitaxial growth.
24 However, little investigations have been made so far on
25 the nucleation process in the III-V system containing N.

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1 During a series of experimental investigations
of growing a III-V mixed crystal layer containing N as a
group V element on an underlying layer, the inventor of
the present invention has discovered that the exposure
5 of the underlying III-V mixed crystal layer, which is
free from N, to an atmosphere containing N is effective
for improving the quality of the desired III-V mixed
crystal that is grown on such an underlying III-V layer.

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10 More specifically, the inventor of the present
invention has discovered that exposure of a III-V
semiconductor layer, which is free from N, to an
atmosphere containing N induces an exchange of some of
the atoms of the group V element on the exposed surface
with N. Thereby, the mixed crystal layer of the desired
15 III-V semiconductor material containing therein N is
grown on such a processed surface of the underlying
layer, without forming defects at the interface between
the underlying layer and the N-containing epitaxial
layer grown thereon. It should be noted that any
20 defects existing on the surface on which an epitaxial
growth of a next semiconductor layer is to be made, is
inherited by the next semiconductor layer.

FIG.25 shows the structure of a specimen 1900
used by the inventor of the present invention for the
25 foregoing experiments. Hereinafter, the present

1 embodiment will be described with reference to a
material system that uses an active layer of GaInNAs.

Referring to FIG.25, the specimen 1900 has a
layered structure formed on an n-type GaAs substrate
5 1901 and includes a buffer layer 1902 of n-type GaAs
formed on the substrate 1901 epitaxially, wherein the
buffer layer 1902 is further covered by an epitaxial
layer 1903 of n-type AlGaAs with a thickness of about
0.2 μm .

10 The AlGaAs layer 1903, in turn, is covered by
an epitaxial layer 1904 of undoped GaAs with a thickness
of about 0.1 μm , and another epitaxial layer 1905 of
undoped GaInNAs is formed further on the GaAs layer 1904
with a thickness of about 7 nm. Thereby, the epitaxial
15 layer 1905 forms a quantum well. The quantum well layer
1905 thus formed has a composition set such that the
quantum well layer 1905 accumulates therein a stress.

On the quantum well layer 1905, there is
formed another epitaxial layer 1906 of undoped GaAs with
20 a thickness of about 0.1 μm , and an epitaxial layer 1907
of p-type AlGaAs is formed further on the epitaxial
layer 1906.

The layered structure of FIG.25 is formed by
incorporating the GaAs substrate 1901 into a deposition
25 chamber of an MOCVD apparatus and supplying various

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1 gaseous source materials into the deposition chamber.

More specifically, the GaAs substrate 1901 is held on a susceptor provided in the deposition chamber, and the growth of the buffer layer 1902 is conducted at the substrate temperature of about 600°C by supplying TMG and AsH₃ into the deposition chamber together with the carrier gas of H₂ as the source materials of Ga and As respectively. After the formation of the buffer layer 1902, a growth of the n-type AlGaAs layer 1903 is conducted while supplying TMA as the source of Al and Si₂H₆ as the n-type dopant, in addition to TMG and AsH₃, and the growth of the GaAs layer 1904 is made further on the AlGaAs layer 1903 by supplying TMG and AsH₃.

After the formation of the GaAs layer 1904, the supply of the source material for the group III elements such as TMG or TMA is interrupted, and the surface of the GaAs layer 1904 is exposed to an atmosphere containing DMHy in addition to AsH₃ while maintaining the substrate temperature to about 600°C, wherein it should be noted that DMHy is used as the source of N in the following process of growing the GaInNAs layer 1905 on the GaAs layer 1904. As a result of such an exposure to the atmosphere containing N, a part of the As atoms on the surface of the GaAs layer 1904 is replaced with N. In other words, the GaAs layer

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1 1904 has a modified surface 1908 having a composition of GaNAs.

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5 After such an exposure of the GaAs layer 1904 to the atmosphere containing N, the growth of the GaInNAs layer 1905 is conducted on the foregoing modified surface 1908 by supplying TMG, TMI, DMHy and AsH₃ respectively as the source materials of Ga, In, N and As. As noted previously, the temperature of the epitaxial growth for the GaInNP layer 1905 is set to
10 about 600°C, wherein it should be noted that the N content in the layer 1905 is increased when the substrate temperature is reduced or the supply rate of DMHy is increased, or the deposition rate is increased. When the deposition temperature is high, the group V
15 elements, particularly N, escape easily from the deposited epitaxial layer. Further, it should be noted that the foregoing epitaxial growth of the GaInNAs layer 1905 is restricted by the bottle-neck process of supplying of the group III elements. Thus, whenever the
20 supply of TMG and TMI is started, the growth of the GaInNAs layer 1905 occurs on the modified surface 1908 of the GaAs layer 1904. As the surface 1908, on which the growth of the GaInNAs layer 1905 occurs, already has the composition of GaNAs, the growth of the GaInNAs
25 layer 1905 occurs without forming defects at the

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1 interface between the layer 1904 and layer 1905, and the
GaInNAs layer 1905 is grown with substantially free from
defects.

5 In the foregoing experiments, the process of
modifying the surface 1908 of the GaAs layer 1904 was
conducted by exposing the surface of the GaAs layer 1904
to the atmosphere containing N for about 30 seconds,
wherein the atmosphere used for the exposure contained
DMHy and AsH₃ with the proportion identical with the
10 atmosphere used for growing the GaInNP layer 1905
thereon.

FIG.26 shows the PL spectrum observed for the
specimen of FIG.25 (curve B) in comparison with the PL
spectrum of a specimen having a similar structure except
15 that the step of exposure to the N-containing atmosphere
is omitted (curve A), wherein it should be noted that
the curve A is represented with a scale ten times as
large as in the case of curve B.

Referring to FIG.26, it can be seen that the
20 intensity of the PL spectrum is increased in the case of
the curve B by the factor of about ten as compared with
the case of the curve A, clearly indicating the improved
quality of the GaInNP mixed crystal layer 1905 thus
grown on the GaNAs surface 1908. As noted already, the
25 result of FIG.26 of improved crystal quality of the

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1 GaInNAs mixed crystal layer 1905 is believed to be the
outcome of the improved crystal quality, including the
effective suppressing of vacant site formation for the
group V elements, at the foregoing interface 1908
5 modified to have the composition of GaNAs.

FIG.27 shows the SIMS profile for the
structure of FIG.25 taken from the top surface of the
GaAs layer 1906.

Referring to FIG.27, it can be seen that the
10 GaInNAs layer 1905 is more or less uniformly doped with
N for substantially the entire thickness thereof. As
can be seen from FIG.27, the top part of the GaAs layer
1904 corresponding to the processed surface 1908
includes a substantial amount of N and in fact has the
15 composition of GaNAs.

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Further, the result of FIG.27 indicates that
the GaInNAs layer 1905 contains therein a substantial
amount of C, while the profile of C shows that there
exists a peak of C concentration in the GaInNAs layer
20 1905 at the bottom part thereof adjacent to the
foregoing GaNAs interface 1908. It is believed that the
C concentration in the GaInNP layer 1905 arises due to
the methyl group contained in DMHy used for the source
of N in the growth of the GaInNP layer 1905. The result
25 of FIG.27 suggests that such an incorporation of C into

1 the III-V layer occurs inevitably when a part of the
group V elements is replaced with N in the epitaxial
growth process of the III-V layer.

It should be noted that the foregoing exposure
5 process of the GaAs layer 1904 is not limited to 30
seconds but can be set to any arbitrary duration as long
as a clear PL intensity is obtained.

[SEVENTEENTH EMBODIMENT]

10 FIG.28 shows the construction of an SQW laser
diode 2000 having an SCH structure according to a
seventeenth embodiment of the present invention.

Referring to FIG.28, the laser diode 2000 is
constructed on a GaAs substrate 2011 and includes a
15 buffer layer 2012 of the n-type grown epitaxially on the
GaAs substrate 2011, wherein the buffer layer 2012
carries thereon a lower cladding layer 2013 of n-type
AlGaAs grown epitaxially on the buffer layer 2012 with a
composition of $\text{Al}_{0.4}\text{Ga}_{0.6}\text{As}$ and with a thickness of 1.5
20 μm , and a lower optical waveguide layer 2014 of undoped
GaAs is formed further on the lower cladding layer 2014
epitaxially with a thickness of about 120 nm.

It should be noted that the epitaxial layers
2012 - 2014 are grown on the GaAs substrate 2011
25 consecutively by an MOCVD process while supplying TMG

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1 and/or TMA as the source of Ga and Al together with AsH₃
as a source of As, wherein the surface of the optical
waveguide layer 2014 thus formed is processed by
exposing to an atmosphere that contains AsH₃ and DMHy
5 while maintaining the substrate temperature of about
600°C for about 60 seconds. During this exposure
process, the supply of the group III elements is
suppressed and there occurs no substantial growth of the
III-V crystal layer on the optical waveguide layer 2014.
10 As a result of such an exposure to the atmosphere
containing N and As, a part of the atoms on the surface
of the layer 2014 is replaced with N as demonstrated in
the SIMS profile of FIG.27 and there is formed a thin
layer 2022 of GaNAs on the surface of the optical
15 waveguide layer 2014. As the atmosphere contains also
AsH₃, such an exposure process does not induce formation
of vacant site for the group V element in the layer
2022, and the layer 2022 provides an excellent surface
for further epitaxial growth of a III-V semiconductor
20 layer thereon.

After such a processing of the surface of the
GaAs optical waveguide layer 2014 to form the GaNAs
layer 2022, an epitaxial growth of an active layer 2015
of undoped GaInNAs layer 2015 is conducted on the layer
25 2022 by an MOCVD process that uses TMG and TMI for the

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1 source materials of Ga and In and AsH₃ and DMHy as the
source materials of As and N. Typically, the active
layer 2015 is formed with a composition of
Ga_{0.8}In_{0.2}N_{0.02}As_{0.98} and has a thickness of about 10
5 nm. Thereby, the active layer forms a quantum well
characterized by quantum levels formed therein for
electrons and holes. It should be noted that the active
layer 2015 having such a composition accumulates therein
a compressive strain of about 1%. Thereby, there is
10 formed a type-I heterojunction at the interface between
the GaInNAs active layer 2015 and the underlying GaAs
optical waveguide layer 2014.

On the active layer 2015 thus formed, there is
formed an upper optical waveguide layer 2016 of undoped
15 GaAs epitaxially with a thickness of about 120 nm, and
an upper cladding layer of p-type AlGaAs having a
composition of Al_{0.4}Ga_{0.6}As is formed further on the
upper optical waveguide layer 2016 epitaxially with a
thickness of about 1.6 μm.

20 On the upper cladding layer 2017, there is
formed a contact layer 2018 of p-type GaAs epitaxially
with a thickness of about 0.3 μm, and an insulating film
2020 of SiO₂ is formed on the contact layer 2018. The
contact layer 2018 is formed with a stripe opening
25 extending in the longitudinal direction of the laser

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1 diode, and a p-type electrode 2019 is formed on the
insulating film 2020 in ohmic contact with the GaAs
contact layer 2018 at the stripe opening in the
insulating film 2020. Further, an n-type electrode 2021
5 is provided on the bottom surface of the substrate 2011
in ohmic contact therewith.

In the laser diode 2000 of FIG.28, it should
be noted that the active layer 2015 of GaInNAs forming
the SQW structure has an excellent quality for the
10 crystal and the optical loss caused by non-optical
recombination of the carriers is minimized. As a result
of use the active layer 2015 of GaInNAs containing N
therein, a large band discontinuity is guaranteed in the
conduction band at the heterojunction interface to the
15 underlying GaAs optical waveguide layer 2014 or the
overlying GaAs optical waveguide layer 2016, there
occurs an effective confinement of electrons in the
active layer 2015 and the preferable feature of high
efficiency of laser oscillation is maintained even when
20 the laser diode 2000 is operated in the room temperature
environment. The laser diode 2000 of the present
embodiment produces an optical beam with the optical
wavelength band of 1.3 μm .

In the present embodiment, it should be noted
25 that the deposition process of the epitaxial layers 2012

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1 - 2018 is by no means limited to the MOCVD process
described but an MBE process may be used similarly.
Further, the active layer 2015 is by no means limited to
have the SQW structure but may have an MQW structure.

5

[EIGHTEENTH EMBODIMENT]

FIG.29 shows a semiconductor layered structure
according to an eighteenth embodiment.

As explained with reference to FIG.10, there
10 occurs a remarkable concentration or segregation of N
when a GaInP layer is grown epitaxially on an underlying
AlGaInP layer by an MOCVD process, indicating that there
exists a strong interaction between Al in the AlGaInP
layer and N that is supplied to the surface of the
15 AlGaInP layer together with other source elements of the
GaInP layer.

The result of FIG.10 thus indicates that the
content of N to be incorporated into the III-V epitaxial
layer can be increased significantly when Al is
20 incorporated into the III-V epitaxial layer as the group
III element. Due to the increased content of N, the
degree of freedom for designing the band structure of
the III-V epitaxial layer is increased substantially,
and various band structures that have not been realized
25 hitherto may be obtained.

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1 Referring to FIG.29, it can be seen that there
is provided an epitaxial layer 2111 of AlGaInP, on which
an epitaxial layer 2102 of AlGaInP and an epitaxial
layer 2101 of AlGaInNP are deposited epitaxially and
5 consecutively, wherein the epitaxial layer 2101 has a
composition represented by the compositional parameters
 x_1 , y_1 and z_1 as $\text{Al}_{x_1}\text{Ga}_{y_1}\text{In}_{(1-x_1-y_1)}\text{N}_{z_1}\text{P}_{(1-z_1)}$, the
epitaxial layer 2111 has a composition represented by
the compositional parameters x_2 and y_2 as $\text{Al}_{x_2}\text{Ga}_{y_2}\text{In}_{(1-x_2-y_2)}\text{P}$, and the epitaxial layer 2102 has a composition
10 represented by the compositional parameters x_3 and y_3 as
 $\text{Al}_{x_3}\text{Ga}_{y_3}\text{In}_{(1-x_3-y_3)}\text{P}$, in which the compositional
parameters are set so as to satisfy the relationship $0 \leq$
 $x_1 < 1$, $0 \leq x_3 < x_2$, $0 < y_1 \leq 1$, $0 \leq y_2 < 1$, $0 < y_3 \leq 1$,
15 and $0 < z_1 < 1$.

Further, the epitaxial layer 2102 is provided
on the epitaxial layer 2101, and an epitaxial layer 2103
having a composition identical with that of the
epitaxial layer 2111 is provided on the epitaxial layer
20 2101.

In the construction of FIG.29, the energy
level of both of the conduction band and valence band is
decreased in the AlGaInNP epitaxial layer 2101 as a
result of incorporation of N as explained before.
25 Thereby, it should be noted that the amount of N to be

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1 incorporated in the epitaxial layer 2101 is increased
significantly due to the presence of Al in the epitaxial
layer 2101, and the degree of freedom of band structure
designing is increased substantially. Further, in view
5 of the improved efficiency of incorporating N into the
epitaxial layer 2101, only a small amount of N source is
used for causing a substantial modification of the band
structure of the layer 2101. Thereby, the cost of
forming the semiconductor layered structure of FIG.29 is
10 reduced also.

As noted already with reference to FIG.10, the
existence of Al in the layer underlying the layer that
contains N causes a severe deterioration in the quality
of the N-containing layer grown thereon due to the
15 segregation of N at the interface between the N-
containing layer and the underlying layer. Thus, in the
structure of FIG.29, the Al content x3 of the layer 2102
underlying the AlGaInNP layer 2101 is reduced
substantially as compared with the Al content x2 of the
20 epitaxial layer 2111 further underlying the layer 2102.
The Al content x3 of the layer 2102 may be zero as well.
Thereby, the segregation of N at the interface between
the AlGaInNP layer 2101 and the underlying layer 2102 is
successfully suppressed and the AlGaInNP layer 2101 can
25 be grown with an excellent quality. Further, by

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1 interposing such an intermediate layer 2102 between the
epitaxial layer 2111 of AlGaInP and the AlGaInNP layer
2101, it becomes possible to increase the Al content x2
without problem. By increasing the Al content x2, the
5 bandgap of the layer 2111 is increased substantially.
It should be noted that the intermediate layer 2102 may
have small thickness just enough for covering the
surface of the layer 2111.

FIG.30 shows the layered structure of FIG.29
10 in more detail, wherein FIG.30 shows the layered
structure as applied to a light-emitting device.

Referring to FIG.30, the layered structure of
FIG.29 is constructed on a GaAs substrate 2105 covered
by a buffer layer 2104 of GaAs, wherein an AlGaInP layer
15 2111a having a thickness of 0.1 μm and a composition of
(Al_{0.5}Ga_{0.5})_{0.5}In_{0.5}P is formed epitaxially on the
buffer layer 2104 in correspondence to the layer 2111 of
FIG.29 as a lower cladding layer, an intermediate layer
2102a of AlGaInP having a thickness of 4 nm and a
20 composition of (Al_{0.1}Ga_{0.9})_{0.5}In_{0.5}P is formed
epitaxially on the AlGaInP layer 2111a in correspondence
to the layer 2102 of FIG.29, and the AlGaInNP layer 2101
having a thickness of 30 nm and a composition of
(Al_{0.2}Ga_{0.8})_{0.5}In_{0.5}N_{0.002}P_{0.998} is formed on the
25 intermediate layer 2102a in correspondence to the

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1 AlGaInNP layer 2101 of FIG.29. On the AlGaInNP layer
2101, there is formed an AlGaInP intermediate layer
2102b substantially identically with the intermediate
layer 2102a, and an AlGaInP layer 2103b is formed
5 further on the AlGaInP intermediate layer 2102b
similarly to the intermediate layer 2103a as an upper
cladding layer.

In the structure of FIG.30, a semi-insulating
GaAs single-crystal having a surface inclined with
10 respect to the (100) surface in the $\langle 011 \rangle$ direction with
an angle of about 15° is used for the GaAs substrate
2105. The structure of FIG.30 is typically formed by an
MOCVD process while using TMG for the metal organic
source of Ga, TMA for the metal organic source of Al,
15 TMI for the metal organic source of In, PH_3 as the
gaseous source of P, and DMHy as the organic source of
N, together with a carrier gas of H_2 , wherein the
deposition of the epitaxial layers is typically
conducted at a temperature of about 750°C , which is
20 substantially higher than the conventional temperature
used for growing an N-containing III-V layer of about
 650°C . In the foregoing growth process, it is also
possible to use MMHy (monomethylhydrazine) for the
organic source of N.

25 FIG.31 compares the amount of N incorporated

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1 into an AlGaInP epitaxial layer having a composition of
(Al_{0.2}Ga_{0.8})_{0.5}In_{0.5}P in comparison with the case of a
GaInP epitaxial layer having a composition of
Ga_{0.5}In_{0.5}P.

5 Referring to FIG.31, it can be seen that the
amount of N incorporated into the GaInP epitaxial layer
increases with increasing mole ratio of DMHy with
respect to PH₃ defined as [DMHy]/([PH₃] + [DMHy]).
Further, there is a tendency that the amount of N thus
10 incorporated increases with decreasing deposition
temperature of the GaInP epitaxial layer.

On the other hand, FIG.31 also represents a
remarkable result in that, when Al is contained in the
epitaxial layer, the amount of N thus incorporated
15 increases sharply even in the case the mole ratio of
DMHy is as low as about 1%. This result is in good
agreement with the result of FIG.10 indicating the
segregation of N at the interface between the AlGaInP
layer and the GaInNP layer grown thereon.

20 In the structure of FIG.31, it should be noted
that the quality of the AlGaInNP epitaxial layer 2101
would be deteriorated substantially when the
intermediate layer 2102a is omitted, because of
extensive formation of rough surface. However, this
25 problem is successfully avoided by interposing the

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1 intermediate layer 2102a with a reduced or zero Al-
content, and the AlGaInNP epitaxial layer 2101 thus
grown on the intermediate layer 2102a shows a mirror
flat top surface. As noted already, the thickness of
5 the intermediate layer 2102a can be very small such as 4
nm as noted above, as long as the intermediate layer
2102a covers the top surface of the underlying AlGaInP
cladding layer 2111a uniformly.

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The light-emitting device of FIG.30 is driven
10 by injecting electrons and holes into the AlGaInNP
active layer 2101a respectively from the lower cladding
layer 2111a and the upper cladding layer 2103b and shows
a PL wavelength offset in the longer wavelength
direction due to the incorporation of N in the active
15 layer 2101a. Because of the mirror flat surface
achieved for the intermediate layer 2102a and the active
layer 2101a, the light-emitting device of FIG.30
achieves a high efficiency of light emission.

Further, because of the large band
20 discontinuity in the conduction band at the interface
between the active layer and the adjacent intermediate
layer 2102a or 2102b and thus the adjacent cladding
layer 2111a or 2103b, the overflowing of carriers from
the active layer 2101 is effectively minimized and the
25 efficiency of light emission is improved substantially,

1 similarly to the previous embodiments due to the
incorporation of N into the active layer 2101.

Further, the light-emitting device of FIG.30
can decrease the optical wavelength while simultaneously
5 maintaining the large band discontinuity, by
incorporating Al and N simultaneously into the active
layer 2101. It should be noted that N causes a downward
shifting of the conduction band energy and valence band
energy and further the decrease of the bandgap energy,
10 while Al compensates for the decrease of the bandgap
energy. Thereby, the light-emitting device of FIG.30
produces a short wavelength optical beam with a high
efficiency of emission.

It should be noted that the structure of
15 FIG.29 or 30 can be formed also by an MBE process.
Further, the source of N is not limited to DMHy but
other N-containing compounds such as NH_3 may also be
used.

20 [NINETEENTH EMBODIMENT]

FIG.32 shows the construction of an edge-
emission-type stripe laser diode according to a
nineteenth embodiment of the present invention in a
cross-sectional view as viewed in an axial direction.

25 Referring to FIG.32, the laser diode is

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1 constructed on a substrate 2310 of n-type GaAs having an
inclined surface similar to the one described with
reference to FIG.29, and includes a lower cladding layer
2308 of n-type AlGaInP having a thickness of 1 μm and a
5 composition of $(\text{Al}_{0.7}\text{Ga}_{0.3})_{0.5}\text{In}_{0.5}\text{P}$ formed on the GaAs
substrate 2310, a lower optical waveguide layer of
undoped AlGaInP having a thickness of 0.1 μm and a
composition of $(\text{Al}_{0.5}\text{Ga}_{0.5})_{0.5}\text{In}_{0.5}\text{P}$ formed on the lower
cladding layer 2308, and a lower intermediate layer
10 2302a of undoped AlGaInP having a thickness of 4 nm and
a composition of $(\text{Al}_{0.1}\text{Ga}_{0.9})_{0.5}\text{In}_{0.5}\text{P}$ formed on the
lower optical waveguide layer 2311, and an active layer
2301 of undoped AlGaInP having a composition of
 $(\text{Al}_{0.2}\text{Ga}_{0.8})_{0.5}\text{In}_{0.5}\text{N}_{0.002}\text{P}_{0.998}$ is formed on the lower
15 intermediate layer 2302a with a thickness of about 30
nm.

Further, on the active layer 2301, there is
formed an upper intermediate layer 2302b of undoped
AlGaInP with composition and thickness similar to those
20 of the lower intermediate layer 2302a, and an upper
optical waveguide layer 2303 of undoped AlGaInP is
formed further on the upper intermediate layer 2302b
with thickness and composition similar to those of the
lower optical waveguide layer 2311. On the upper
25 optical waveguide layer 2303, there is formed an upper

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1 cladding layer 2304 of p-type AlGaInP with composition
and thickness similar to those of the lower cladding
layer 2308 except for the conductivity type, and a
contact layer 2305 of p-type GaAs is formed further on
5 the upper cladding layer 2304.

The GaAs contact layer 2305 is covered with an
SiO₂ film 2306 having a contact window exposing the
contact layer 2306, and a p-type electrode 2307 is
provided on the SiO₂ film 2306 in contact with the
10 contact layer 2306 at the contact window. Further, an
n-type electrode 2310 is provided on the bottom surface
of the substrate 2309.

In the structure of FIG.32, it should be noted
that the optical waveguide layer 2311 corresponds to the
15 epitaxial layer 2111 of FIG.29, the intermediate layer
2302a corresponds to the epitaxial layer 2102 of FIG.29,
the active layer 2101 corresponds to the epitaxial layer
2101 of FIG.29, the intermediate layer 2102 corresponds
to the epitaxial layer 2102 of FIG.29, and the optical
20 waveguide layer 2303 corresponds to the epitaxial layer
2103 of FIG.29.

The laser diode of FIG.32 has an advantageous
feature of effective electron confinement in the active
layer 2301 and simultaneously an advantageous feature of
25 increased bandgap energy for emitting a short wavelength

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1 laser beam as a result of simultaneous incorporation of
Al and N into the active layer 2301.

[TWENTIETH EMBODIMENT]

5 FIG.33 shows the construction of an edge-
emission-type stripe laser diode according to a
twentieth embodiment of the present invention in an
axial cross-sectional view, wherein those parts
corresponding to the parts described previously are
10 designated by the same reference numerals and the
description thereof will be omitted.

Referring to FIG.33, the laser diode of the
present embodiment has a construction similar to that of
FIG.32, except that undoped InGaP layers 2302c and 2302d
15 having a composition of $\text{Ga}_{0.65}\text{In}_{0.35}\text{P}$ are used in place
of the AlGaInP intermediate layers 2302a and 2302b. By
using the composition entirely free from Al for the
intermediate layers 2302c and 2302d, the quality of the
N-containing active layer 2301 is improved and the
20 efficiency of laser oscillation is also improved.

While the present embodiment is explained with
reference to a material system that uses GaInNP for the
active layer, it should be noted that a similar result
is obtained also for other systems that uses other N-
25 containing III-V material such as GaInNAs for the active

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1 layer. In this case, a photon emission in the optical
wavelength band of 1.3 μm becomes possible.

Further, the present invention is not limited
to those embodiments described heretofore, but various
5 variations and modifications may be made without
departing from the scope of the invention.

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